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Swedish shale oil

Production methods in Sweden

Technical Assistance Mission No 93

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SUMMARY

FOREWORD

THE MISSION

ORIGIN OF THE MISSION

During the 3rd session (19th-20th October, 1950) of Working Party No. 7 of the Machinery Committee (Technical Assistance), a cordial invitation for a visit to Sweden to study the new Swedish Shale Oil production methods used at Kvarntorp was extended to the Member countries of O.E.E.C. by the Delegate for Sweden, Mr. Quistgaard, Managing Director of the Swedish Shale Oil Centre.

Subsequently the Swedish memorandum on shale oil was circulated to members of the Oil Committee, this memorandum, provided by Mr. Quistgaard, containing detailed information on the installations and output of an industry which, since its inception in 1941, had grown to considerable proportions.

The Oil Committee, at its 55th meeting on 25th January, 1951, examined the Swedish memorandum, together with a proposed itinerary for a visit to Kvarntorp, which would be sponsored by the Kvarntorp plant and the Swedish Centre for Technical Assistance to O.E.E.C. countries.

At that meeting only the Luxembourg delegation was in a position to show immediate interest in the proposal, but at the 58th meeting on 18th May, 1951, the Delegations of Austria, the United Kingdom, Western Germany and Norway also expressed their interest.

It was agreed, therefore, at this 58th meeting, to form an intra-European Technical Assistance Mission to visit Sweden for the purpose of studying shale oil production methods there. Finally the Oil Committee,

at its 59th meeting on 20th June, 1951, considered the project letters containing full particulars of the Mission, the proposed programme and the draft Resolution of the Executive Committee. The Committee adopted the suggested programme and the draft Resolution and agreed to submit to the Technical Assistance Group the name of Dr. D. Stewart, expert from the United Kingdom, as a Secretary for the Mission.

The project was approved by the Executive Committee of O.E.E.C., and ultimately the Mission met in Stockholm on the evening of 22nd October, 1951. On the following morning the Mission travelled to Kvarntorp where are situated the shale deposits which are being worked by Svenska Skifferolje A.B. (Swedish Shale Oil Co.).

During the next two and a half days the members had the opportunity of studying intensively every phase of the Company's operations, from mining of the shale to the production of Liquefied Petroleum Gas, Gasoline, Fuel Oil, Sulphur, Lime, etc.

Preceding inspection of each section of the works and mining operations the members of the Mission listened to lectures by senior members of the Company's technical staff, describing the processes and plant to be inspected. They also had the advantage of access to a large illustrated flow diagram of the shale oil and by-product production processes which covered two walls of the lecture room at Kvarntorp. The subjects of these lectures and the names of the lecturers are as follows:

Tuesday, 23rd October, 1951	"Our Energy Sources and Resources". By Prof. E. Schjänberg, Director of Research, Svenska Skifferolje A.B.
	"Mining and Crushing of oil Shale at Kvarntorp", by Mr. Hans Grebius, Chief Mining Engineer, Svenska Skifferolje A.B.
Wednesday, 24th October, 1951	"Retorting Methods employed at Kvarntorp", by Mr. C. Gejrot, President, Svenska Skifferolje A.B.
Thursday, 25th October, 1951	"Some Research Problems which have been studied at Kvarntorp", by Prof. E. Schjänberg, Director of Research, Svenska Skifferolje A.B.

During the visits to plant and at a final discussion meeting, the conducting officials freely answered the many questions put to them. The thanks of the Mission are due to the Directors of the Svenska Skifferolje A.B. for permission to visit the plant at Kvarntorp and to those officials who spent so much time and effort in making the visit a success.

After the visit to the shalefield, the Mission travelled to Kolsva, where they inspected the boiler making plant of Messrs. Svenska Maskinverken A.B. at the invitation of the directors of this firm. In this plant are made the La Mont tube nests used for steam generation in the furnaces of the newest types of Kvarntorp retorts.

The names of the members of the Mission are:

	AUSTRIA
Dr. Ing Otto Kaiser	Employee of the Federal Ministry for Trade and Reconstruction, Chief, Mining Dept. Neuer Markt 9/9, Wien, I.
Maximilian Schatz	Manager, Maximilian Schatz, Reith near Seefeld, Maximilianshütte
	BELGIUM
Prof. E.J. Mertens	Professor of Industrial Chemistry at University of Louvain. 10 rue Marie-Thérèse, Louvain.
	GERMANY
Dr. Herbert Beyer	Engineer, Dr. C. Otto & Co. Bochum. Bochum, Zeppelinstrasse 29, Germany.
Dr. Walter Gollmer	Export on questions of high and low temperature carbonisation at German Coal Management, Essen. Essen-Steele, Bochumerstr. 191, Germany

	LUXEMBOURG
Mr. François Mandres	Engineer. rue Marie-Adelaide, 9, Luxembourg.
	NORWAY
Gunnar Ranke	Process Superintendent, Valloy Oil Refinery. Ostlanaske Petroleum Company, Valloy.
	NETHERLANDS
Prof.W.J.D. Van Dijck	General Adviser to Management BPM on Research of Royal/Dutch Shell Group. 31 Willem de Zwijgerlaan, The Hague.
Ir.W.Th.B. Reimering	Engineer with BPM. Special Studies in Production Dept. Ruychrocklaan 193, The Hague.
	TURKEY
Nahid Kiragli	Chemical Engineer. M.T.A. Enstitusu, Ankara.
	UNITED KINGDOM
Dr. D. Stewart	Deputy Chief Chemist, Scottish Oils Ltd. Middleton Hall, Uphall, West Lothian, Scotland.

THE SWEDISH SHALE OIL INDUSTRY IN RELATION TO SHALE OIL PRODUCTION IN OTHER PARTS OF THE WORLD

Processes for the production of oil from coal were patented in Britain as early as the 17th century. The first shale oil plant, however, was started by Selligue in France about the year 1938, employing the bituminous schists of Autun. A shale oil industry exists in France at the present day, the scenes of operations being: (1) at St. Hilaire in the centre of the country, (2) At Autun, north-east of St. Hilaire, and (3) Severac-le-Château, in the south central district. The deposits of St. Hilaire and Autun are of Permian age, but those at Severac-le-Château are more recent geologically, being found in Lias formations. The retorts in use at the three existing plants are entirely different in principle. Modified Scottish type retorts are in use at Autun, a vertical retort heated internally by the circulation of hot gas at St. Hilaire and a form of rotating tubular retort at Severac-le-Château. The oil yield from the French shale deposits is from 5% to 10% by weight.

In the year 1851, an industry was started by Dr. Young at Bathgate, Scotland, for the production of oil from Boghead Coal or Torbanite, the latter name being derived from the estate of Torbanehill on which the mineral was found. Following the exhaustion of the Torbanite in the area about the year 1862, the Carboniferous oil shales of the Lothians were used as the raw material for the industry. The Shale oil industry in Scotland developed very rapidly in the second half of the 19th century and in the years 1860-1870 about 60 works were in operation, producing oil from shale or preparing finished oil products from the crude oil. Scottish shale oil is paraffinic in nature and is obtained in 8-9% yield on the shale retorted. The industry to-day is in the hands of one Company, which mines about 1.5 million tons of shale annually and produces a range of products such as gasoline, diesel oil, wax, synthetic detergents and building bricks. The retorts favoured by the Scottish industry are of the vertical static type, heated both internally and externally.

In Estonia the very large deposits of oil shale (Kukersite) were actively worked from about the year 1921, and in 1938 six separate companies were engaged in the industry. The deposits of Kukersite extend eastwards into the U.S.S.R. where there is a shale oil plant in operation at Slantsa beyond the River Narva. The oil from Estonian shale is of a heavy asphaltic nature, containing no wax. The yield, however, has been reported as high as 29% on the shale by Fischer assay. The retorts used in Estonia vary from the static internal combustion type to rotating externally heated tubes, and the well-known Tunnel Kiln devised by Swedish engineers and presently in use at Kvarntorp.

At Fuschun in Manchuria there are immense deposits of oil shale which have been worked by opencast mining methods from about the year 1926 on a considerable scale. This shale is low grade (5-6% on Fischer assay) and gives an oil of paraffinic nature. The retorts used initially were of the static internally heated type, but up-to-date information is lacking.

Oil shale deposits at Puertollano in the Cuidad Real Province of Spain have been worked since 1922, employing one bench of modified Scottish type retorts. This industry is in process of being greatly increased in size and is being equipped with the latest type of Westwood Scottish retort. The Spanish shale yields from 10-17% on Fischer assay.

In the Ermelo district of the Transvaal in South Africa Torbanite deposits have been worked since 1935 along with a seam of bituminous coal. The Torbanite is pyrolised in rotating externally heated cylindrical retorts and also in externally heated horizontal mechanically raked retorts, originally designed for the low temperature carbonisation of coal.

Until recentl, the Permo-Carboniferous Torbanites of the Capertee valley in New South Wales, Australia, were worked on a considerable scale. The retorts employed were a modified version of the vertical externally heated Scottish type.

Oil shale is found in several areas in Germany, but the two principal beds are near Balingen in Wurttemberg and in the Hanover Basin near Braunscnweig. There is also a smaller deposit near Messel. During and immediately after the second qorld war two mining and retorting plants were in operation near Balingen, handling a Lias shale of about 4.5% oil content. One of these plants used an intermittent downward distillation

internal combustion retort and the other a vertical static retort in which the charge was heated by the passage of superheated steam through it.

The Swedish industry was started as a result of the grave shortage of oil in that country in 1941. In its ten years existence it has experienced remarkable expansion. The methods employed in Sweden are the subject of this report.

In these countries shale oil industries of commercial proportions exist or have until recently existed.

In several other countries also small short-lived industries were started up in some cases only experimental retorting units were erected. In the first category are the extinct industries of New Zealand and Brazil and in the second, experimental retorts were at one time or another set up to assess the value of the oil shales in such countries as Nova Scotia and New Brunswick in Canada and Bulgaria in Eastern Europe.

Many countries have very large reserves of oil shale, the prospecting of which is very incomplete.

In the South-West of the Grand Duchy of Luxembourg there are deposits of oil shale extending over an area of 88-90 sq. km. (31-55 sq. miles). These shales, known as "Schisted a Posidonies", are found in many parts of Europe and are of upper Lias age. The average thickness of the Luxembourg deposits is 10 m., but the mineral gives a yield of up to 5% of oil only. There is about 3 to 4% of pyrites in the shale. The oil has a sulphur content of about 3 1/2% and contains a small quantity of wax.

Very large and rich oil shale deposits are known to exist in Yugoslavia although only one area has so far been well prospected.

This is in the valley of the River Moravitza in the East of the country where the Alexinac shales of upper Oligocene age and of fresh water origin outcrop for about 13 km. (8 miles), dipping at 30 to 45% to the horizontal. These beds are from 80 to 120 m. (262-393 feet) in thickness and the richest shales occur in lenticular formation - up to 25% oil content being reported. The average assay of these beds, however, is from 10 to 15% oil of paraffinic nature with a considerable wax yield and low sulphur content.

Near the town of Valjevo there are 50 to 60 sq. km. (19 to 23 sq. miles) of surface shale beds, 50 to 60 m. (176 ft.) in thickness, about half of this thickness being oil shale proper.

These fresh water shales of Middle Miocene age are suitable for opencast working.

Few details are known about the Upper Cretaceous oil shales which are associated with coals near the town of Zajecar in Eastern Serbia. The total thickness of these beds is from 60 to 80 m. (196-262 ft.) containing about 20 m. (66 ft.) of oil shales of marine origin.

Interest has in recent years been taken in the Trassic oil shales of the Belgian Congo. The oil shale basin near Stanleyville covers on area of 1,400,000 hectares (3,459,000 acres). Prospecting has revealed the existence of eleven seams of a total thickness of nearly 10 m. (32.8 feet). The shale seams are separated by barren deposits of variable thickness. The oil yield varies from one seam to another and also horizontally in individual seams. Analyses so far carried out have indicated a yield of about 10% of oil.

Large deposits of bituminous shales of undefined quality are also known to exist in the Mayumbe region.

The extent and utilisation of the vast oil shale deposits of Colorado, Utah and Wyoming have been investigated by industry and by the United States Department of the Interior since 1944. Laboratory research work on oil shale is being carried on at the Petroleum and Oil Shale Experimental Station at Laramie, Wyo., and an underground quarry, experimental shale oil refinery and retorting plant have been in operation for several years amid towering cliffs of oil shale at the Oil Shale Demonstration Plant near Rifle, Colorado. At Rifle a 50 ft. (15 1/2 m.) seam of rich oil shale is being extracted in the underground quarry by methods developed there, and the extent of the operations may be judged from the fact that this mine produced 58,500 tons of shale in 1950. (1)

In the retorting research programme carried out over the last few years, a number of retorting principles have been investigated and pilot plants have been operated. So far the requirement of a large specific throughput per unit has favoured the use of static internally heated retorts. The use of externally heated distillation gases for transferring heat to the shale in the retort was in favour initially. This principle involved the use of an external furnace for the recovery

of heat from the shale coke (de-oiled shale). More recently, combustion of the free carbon in the de-oiled shale in the retort itself has been used to supply the heat for retorting, the heat carrier and temperature controller being recirculated permanent gas, some of which is also burned inside the retort.

Some interesting retorts have also been produced by industrial interests in the United States, notably the continuous downward distillation vertical retort devised by the Union Oil Co; in California. This unit, of the internally heated type, is notable for the fact that the shale passes upwards through the retort counter current to the downward movement of the gases.

These principles of retorting are in contradistinction to those of the Bergh and Kvarntorp retorts used by the Swedish Shale Industry, where the retorts are externally heated only and combustion gases are not mixed with distillation gases from the shale. American and Swedish methods thus represent two distinct schools of though on the difficult subject of retorting of minerals for the recovery of oil. The retorts presently used in Scotland embody both principles, but in addition are designed to give maximum yields of ammonia as well as oil - a feature not considered in either the American or Swedish projects owing to the low nitrogen content of these shales.

Any study of retort design must always take into consideration the chemical and physical peculiarities of the shale that is to be pyrolised. Thus the main American requirement is a retort which will be cheap to build and maintain and which will give a maximum yield of oil in very large quantities per unit. Shale ash fusion is not troublesome and ammonia production need not be considered, whereas fuel economy would probably be confined to making the retorting process self-supporting.

In the case of Swedish shale, fusion of the ash is a potential source of trouble, but the large proportion of free carbon suggest the recovery of the heat in this fuel and the high sulphur content is an important factor.

To countries considering the utilisation of domestic deposits of oil shale, the importance of a study of both American and Swedish ideas in retorting is evident.

The sending of the O.E.E.C. Mission No. 93 to Sweden to study production methods there is the first step in such a study.

REPORT ON VISIT OF MISSION NO. 93 TO THE SWEDISH OIL INDUSTRY - OCTOBER, 1951

LOCATION OF SWEDISH SHALE OIL INDUSTRY

Although oil shale occurs in vast quantities in several parts of Sweden, the present operations are carried out at Kvarntorp which is about 15 miles South of Örebro in the province of Narke in Central Sweden. Figure 1 shows the location of this shale deposit in relation to the principal Swedish towns.

The shale is of Cambrian/Silurian age and is found so near the surface that the open pit method of mining can be employed. The area of the oil shale deposits in Narke province is given as 38.6 sq. miles (2) with an average thickness of 10 metres (32.8 feet) and the quantity of oil in this shale is estimated to be 80 million tons or 500 million barrels. (3)

The country around Kvarntorp where the shale is being worked is flat, but is pleasantly broken up by small forests of pine and birch trees. The population in the district is very sparse and the inhabitants live mostly in isolated wooden houses, each with its own small area of cultivated land.

MINING METHODS

The oil shale bed which is being worked in Kvarntorp is from 10 to 16 m. in thickness (32.8-52.5 feet) and is inclined at less than 1^{o} to the horizontal. The overburden at the open mine is 6-8 m. thick (19.7-26.2 ft.), of loose soil, gravel and peat, and on the average 0.4 cu. m. of overburden (approximately .84 tons) must be handled per ton of shale. The lowest 8 m. (26.2 ft.) of shale gives approximately 6½% of oil on Fischer assay as compared with 4½% for the remainder. The average oil content (Fischer) of the broken shale during the last three years has been 5.8%.

The shale is essentially argillaceous, but contains irregular pieces of a low grade limestone, amounting to about 15% by wt. of the seam. The larger pieces of limestone are separated at the mine and left

there, but the remainder is removed by hand after preliminary crushing of the shale.

In 1951 the output of raw shale was 1,800,000 tons and this is expected to rise to 2,500,000 tons in a year. The total quantity of shale available in Narke is estimated at about 1 billion tons. A section of the shale field is shown in Figure 2.

Mining in a new area is started by making a canal in the overburden and shale bed about 75 m. (246 feet) wide. Using a 3 cu. metre (3.9 cu. yd.) Bucyrus Monighan dragline with an action radius of 40 metres (125 ft.) the overburden is removed from the next strip and dumped into the open canal. Thus the top of the shale is exposed for mining. After the first cut of shale is taken out, the operations are carried on from the floor of the open quarry on which the 4 cu. metre (5.2 cu. yd.) shovel runs and on which a main line gauge railway track is laid. The dragline remains at the top of the quarry, removing overburden, and the shale mining shovel and the rails for the shale wagons are moved forward as the face advances. The whole vertical shale face is mined in one cut and the rock is loosened for digging by drilling and shot-firing. The consumption of explosives is about 200 gr./cu. m. (0.21 lb. per ton).

The shale is loaded by one of two 4 cu. m. electrically operated shovels mounted on caterpillar tracks. The shovels were made by Menck and Hambrock of Hamburg, and each can handle about 400 tons per hour. The shale is loaded on to 7 car trains of specially designed side tipping trucks drawn by an electric locomotive fitted with a pantograph collector taking current from an overhead conductor. The seven-car train takes approximately 130 tons of shale ($18\frac{1}{2}$ tons per car) and is loaded in 12 minutes. At present the shale trains have a run of about 1/4 mile to the preliminary breaking plant, which is situated at the bottom of the quarry adjacent to the retorting and refining plant. Figure 3 shows the dragline, shovel and train of wagons in the shale quarry.

OUTPUT OF MINE

The mining and crushing plants work 6 days per week or 12 shifts in all. There are 50 workers in the mine for the present output of 1,800,000 tons per annum, or 5,740 tons per working day, or 4,940 tons per day of 365 per year.

REHABILITATION OF GROUND

At present some of the spent shale is tipped above ground, but most of it is disposed of in the quarry and ultimately all will be handled in this way. Large motor lorries dump the spent shale in worked out areas of the quarry, the overburden and soil being replaced and bulldozed level. Finally, a special variety of poplar tree is planted at intervals of about 5 metres (16 feet). Several areas were inspected near the plant where the shale had been removed, the spent shale and overburden replaced and the trees planted. The ground had a rough appearance, but was no lower in level than the adjacent country.

TRANSPORTATION AND CRUSHING OF THE SHALE

The preliminary crushing plant is situated in a large pit in the shale quarry itself.

Trains of wagons of shale arriving at the breaker pit are detached from the electric locomotive and hitched to a wire rope running round a capstan which is employed to draw the train past the two emptying positions. Two positions and two preliminary breakers are in use, but wagons are emptied at one point at a time, i.e. while a wagon is being emptied at one point, the shale from the emptying of the last wagon at the other point is still feeding down to the crusher. Thus both crushers are actually crushing at the same time and wagons are emptied into their hoppers alternately. On being brought to the emptying position by the wire rope and capstan, a suspended horizontal bar catches on lugs to lift the side door which extends over the whole length of the wagon. A hook then lifts the body of the wagon at the mid point on the other side from the door and tilts it about a metre only. The wheels of the wagon remain on the rails. The bottom of the wagon being of polished steel, the shale slides out at once. The positioning, lifting and replacing of a wagon takes two minutes, whereas the filling of it at the quarry takes $1\frac{1}{2}$ minutes. The wagons are emptied at a rate of 350 tons/hour, but the engineers hope, by reducing the wagon handling time (notably the handling of the side doors) to increase the throughput to 500 tons per hour. Two men operate this equipment at present.

The raw shale is fed down continuously from the wagon emptying hoppers to the preliminary crushers by very heavy chain feeders which are slowly rotated by electric motors. The preliminary crushers are of the jaw type with large fly wheels, and are driven by

electric motors through multi V belts.. They can handle pieces of 150 x 120 cms. (47" x 59") size. These crushers are placed high up from the floor of the breaker pit, which is an immense cavity about 12 m. (40 feet) deep, 12 m. (40 feet) wide and 18 m. (60 feet) long. From the crushers the shale gravitates directly to two double toothed roll crushers at the bottom of the pit. The crushed shale from these machines is about 10-12 cms. (4-5 inches) cube in size and is elevated from below the roll crushers by a pair of conveyor belts a metre wide (3'3"). These run upwards for a distance of about 300 m. to the fine crushing plant, which is situated in the works proper. This plant is in a wooden building and is at present under reconstruction, so that the plant is untidy and noisy. The two belts carrying the crushed shale from the preliminary breaker pit pass through a room in which 8 men pick out by hand the pieces of limestone from the shale. This stone is thrown down large chutes for conveyance by belt to the lime burning kilns. Figure 4 shows the separation of the limestone.

The fine crushers are of the swinging hammer type, two machines working in parallel. The noise and vibration from these machines is very considerable, as they are handling about 175 tons/hour each and reducing the shale to 80 mm. (3") maximum size. Thereafter follows an elaborate screening plant of the vibrating type which separates the crushed product into three grades:-

(a) Less than 3 mm. size (1/8")
(b) 3 to 27 mm. (1/8" to 1.1/8")
(c) 27 to 80 mm. (1.1/8" to 3")

The fines are rejected and returned to the quarry along with the spent shale.

The crushing and screening plant employs 40 workers.

RECOVERY OF SHALE

The overall recovery of usable shale from the deposit in the mine is as follows:-

Of the deposit as found, about 15% by wt. consists of pieces of limestone. Two-thirds of this limestone (i.e. 10% of the total deposit) is left in the mine and one-third (or 5% of the total deposit) is picked out by hand on the picking belts.

Of the crushed shale (lime-free), about 18½% is rejected as fines of less than 3 mm. size. It is hoped to red··· this loss in the future.

Thus at present 85% of the natural deposit is oil shale and 81½% of this, or 69½% of the deposit, is charged to the retorts. It is hoped to increase this percentage recovery in the near future.

STORAGE OF GRADED SHALE

From the screening plant, belt conveyors elevate the two grades of shale to the top of 10 concrete silos, which in toto contain 11,000 tons of shale or more than 48 hours supply to the retorts. The bases of these silos are at ground level and under them are two long tunnels, each housing a belt conveyor for transporting graded shale to the various retorting plants. These retorting units, of three types (described hereafter), have smaller steel or concrete hoppers, usually at one end, from which they are fed at intervals by separate conveyors. The shale silos are shown in Figure 5.

FUTURE PLANS

After the completion of certain improvements which are presently being carried out in existing retorting equipment, it is planned to mine 2,500,000 tons of raw shale per annum by the end of 1952. This also involves changes in the crushing plant, the most important of which is to replace the present two swinging hammer mills by a large Simons gyratory type crusher which will handle up to 500 tons per hour.

Another important point in the new plant is that intermediate screens will remove shale after each crushing, thus reducing the load on the crushers and minimising the make of fines.

The layout of the proposed screening plant is shown in Figure 6.

RECOVERY OF OIL FROM SHALE

Two methods of recovery of oil from the shale are employed at Kvarntorp. In the first, the oil shale is heated in retorts and in the second the oil shale bed is heated in situ by means of electric heaters placed at the bottom of numerous bore holes drilled to the seam. This method was devised by Dr. Ljungstrom after whom it is named. It will be described later.

TYPES OF RETORTS

When the plant was built during the second world war, three types of retort were erected, and

these, along with a modification to one of them, are still in use. The three retorts are named respectively:-

a) The Bergh Retort, and its later mofification, known as the Kvarntorp Retort.

b) The H.G. Retort (or Rockesholm), a much modified Scottish retort (Pumpherston Type).

c) The I.M. (Industrial Methods Ltd.) Tunnel Retort.

Shale of grading 3-27 mm. is used in the Bergh retort and its Kvarntorp modification, while the other two types of retort require the 27-80 mm. size.

The number and approximate throughputs of the retorts presently installed at Kvarntorp are as under:-

a) One house of 1680 Bergh Retorts, handling 600 tons/day or 0.36 ton/retort/day.

b) One house of 1120 Kvarntorp Retorts, handling 1000 tons/day, or 0.89 ton/retort/day.

c) One house of 1120 Bergh Retorts shut down and being converted to Kvarntorp modification.

d) A double bench of 72 Rockesholm Retorts, handling 900 tons/day, or 12.5 tons/retort/day.

e) Two I.M. Tunnel Kilns, each handling 450 tons/day.

The total is thus (600+1000+900+900) = 3400 tons. This corresponds with the stated output of retortable shale from the mine as:-

$$\frac{1,800,000}{365} \times \frac{69.5}{100} \qquad 3,420 \text{ tons/day}$$

When all the existing 3920 Bergh/Kvarntorp retorts are converted to the Kvarntorp modification, these will have a throughput of 3,500 tons/day, or 0.89 ton/retort/day. If the present throughput of the Rockesholm and tunnel retorts is added (1,800 tons/day) the total throughput capacity of the plant will be 5300 tons of graded shale per day.

The planned production of the mine by the end of 1952 was given as 2,500,000 tons per annum (6,850 tons per day of 365 per year), from which it is expected to get 1,850,000 tons of graded shale (73.9% of mine output). This gives an average expected daily charge of 5,070 tons per day to the retorts. Oil will be obtained also by the Ljungstrom method of underground heating.

DESCRIPTION OF RETORTS

The Bergh Retort

This is an externally heated retort consisting essentially of a C.I. tube 200 mm. (7.87") in diameter and 2.2 m. (7.2 ft.) long. It was invented in 1920 by Mr. Sven Bergh, a Swedish mining engineer, and a number of these retorts were in use at the first Swedish Shale Oil Works at Kinnekleva about 1925. It is of interest to note that the essential features of this retort were patented in the McBeath retort (British Patent No. 2788 of 1866) which was in use at a small oil works at Bellsquarry, Midlothian, in the years between 1864 and 1871. The Bergh retort is open at both ends, the upper end terminating in an open raw shale hopper and the lower end in the furnace or oven in which the oil-free shale is burned (see Figure 7). The hot gases from the combustion of this "shale coke" pass round the retort before escaping to the chimney. The upper part of the retort tube acts as a shale preheater and oil production takes place in the lower one-third of the retort. The vapour draw off pipe therefore is made to pass down through the raw shale hopper to a point below the mid point of the retort. Steam in turn is passed down through a small pipe inside the vapour pipe to a point within a few inches of the bottom of the retort tube to act as a seal to prevent mixing of combustion gases with oil vapours.

These retorts are mounted in cells or boxes of five in a row and the shale ash from each 5 retorts or single box is extracted by two toothed rollers which are rotated intermittently by means of a side rod and ratchet gear. Cells of 5 retorts are built into blocks of 14 cells, giving a total of 70 retorts in a block. These blocks are then built end to end in standard benches of either 8 or 12 blocks, giving benches containing 560 or 840 retorts. In each retort house there are two such benches placed in parallel and separated by a platform about 4 m. (12 feet) wide, which covers the space between the two benches. At furnace level there is access to each bench on either side, and by removing a fabricated steel plug one can observe

conditions in each furnace of five retorts. Each retort house therefore contains 2 x 560 = 1120, or 2 x 840 = 1680 retorts. Figure 8 gives an interior view of the charging platform of a 1680 retort house and Figure 9 is a view taken in the same house at furnace level and showing the extraction ratchet gear.

At Kvarntorp there are two retort houses each containing 1120 retorts (Bergh or Kvarntorp modification) and one containing 1680 - a total of 3920 retorts of this type.

The throughput of the unmodified Bergh retorts is approximately 0.36 ton per tube per day, and this is limited, not by the possible rate of distillation, but by the rate and temperature at which the "shale coke" can be burned in the combustion space below the retort tubes. The shale ash melts at about 950°C. (1740°F.) so that care must be taken to restrict the furnace temperature. In the Bergh retort this is done by deliberately using excess air for combustion, a CO_2 content of from 4 to 5% only being usual. In order to moderate the temperature around the retorts also, small shell boilers were originally fitted, but these were replaced by La Mont steam generating tubes as shown in Figure 7.

With the large excess air to the combustion space, the shale leaves the toothed roller extraction gear quite cold and falls on to a continuously running rubber conveyor belt which elevates it to a hopper at the end of the bench.

The open raw shale hoppers at the top of the retorts and under cover of the retort house form a series of transverse shallow troughs and these are filled with shale at two-hourly intervals from an overhead steel conveyor belt and distributing gear. As the retort blocks are built in such a way (Figure 8) that each hopper serves five retorts, a distributing gear is necessary to spread the shale evenly along the hoppers. This is done by an oscillating movement of the chutes which collect the shale from the belt and divert it into the hoppers. The longitudinal movement of the shale collecting gear and chutes is done by a power operated chain system. Automatic electric controls also stop the conveyor belt when the collecting gear and chute unit is passiang over the gap between the retort blocks.

The Kvarntorp Retort

This is a modification of the Bergh retort designed to give greater throughput of shale and to make

better use of the heat from the "shale coke" by raising more steam. These objects have been attained by controlling the temperature of the shale furnace by the insertion of La Mont steam generating tubes. These are actually embedded in the burning shale, although La Mont tubes are also placed high up in the space surrounding each row of five retorts. The increased rate of spent shale combustion enables the throughput to be increased about 2½ times; thus each Kvarntorp retort tube handles 0.89 ton/day.

The principal points in which the Kvarntorp retort differs from the Bergh retort are:-

(a) The division wall in the combustion space of the Bergh retort has been taken out, the combustion space increased in depth and filled with vertical hair pin La Mont tubes. Because the space between the tube hair pins is only about 3" and there is a chance of the shale being held up by the tubes, a pneumatic rapping gear has been installed below each nest of tubes. See Figures 10 and 11.

(b) The La Mont tubes in the space round the retorts have been raised considerably.

(c) The retorts themselves, which were formerly made of cast iron about 3/4" thick with a foot piece of 20% chromium iron, have been replaced by retorts only 3 mm. (1/8") thick and made entirely of a 13% chromium steel. The lower part is still detachable. The life of the C.I. retorts is 6-7 years, but the life of the steel retorts is not yet known.

(d) The sealing steam which was formerly admitted through a long pipe in the vapour offlet is now supplied by a hooded pipe coming up into the foot of the retort from below. This simplifies the vapour pipes and headers.

(e) Air for burning the shale coke was formerly drawn in by chimney draught, but in the Kvarntorp retorts the cellars housing the extraction rollers and spent shale conveyor belts are sealed and air is fed to them under pressure by a forced draught fan.

Notes on the Operation of the Kvarntorp Retorts and Yields obtained

The Company's engineers consider that the Kvarntorp retort is that best suited to treating Swedish oil shale, and all Bergh retorts are being converted to this modification.

Because of the retort tubes being open at both top and bottom their successful operation depends entirely on a careful balance of suctions in the tubes and in the furnace spaces. Too much suction in the retorts draws in hot combustion gases and too little suction mrans that oil vapours pass downwards and burn at the lower end of the tubes. That the system works so well is due to (a) accurate measurement of retort vapour main and flue suctions by dial meters of large size, and (b) very careful grading of the shale, 3 to 27 mm. size (1/8" - 1.1/8") and avoidance of fines. Inspection of a large number of furnaces in two retort houses showed that in a considerable number of cases oil vapours were burning at the bottom of the retort tubes. This probably accounts for the fact that the Kvarntorp (and Bergh) retorts give an actual oil yield of only 80-85% of the Fischer assay as compared with a 100% yield in retorts of different type in the same works. The actual oil yield obtained from the Kvarntorp retorts was given as 12 United States galls./ton (1000 Kg.) which is equivalent to 10.16 Imp. gls. per ton (2240 lbs.)

In addition, 1950 cu. ft. of 560 B.T.U./cu. ft. (5000 K.Cals./Cu.m.) C.V. gas is obtained (before scrubbing and H_2S removal) and approximately 2200 lbs. (1000 Kg.) of steam at 32 atm. and 375°C. (470 p.s.i. and 700° F.).

The flue gases leaving the Kvarntorp retorts are at a temperature of 250°C. (482°F.) as compared with 470°C. (878° F.) leaving the Bergh retorts.

All retort benches are fitted with waste heat boilers consisting of large nests of La Mont tubes inserted in the outlet flues. Because of its entry by a pipe through the burning shale coke, the steam entering the base of the Kvarntorp retorts is superheated to 500°C. (930°F.). Saturated steam was used in the earlier units.

The de-oiled shale leaving the retort tubes to enter the Kvarntorp furnaces contains about 11% of free carbon and has a heating value of 1000/1100 K. Cals./kg. (1800-1980 B.T.U./lb.).

Labour Requirements

The labour required in a 1680 unit Kvarntorp retort house is two men at the retorts and one at the exhausters, condensers and oil/water separators per shift. The men work 42 hours per week on a spread-over system.

The duties of the two retort men are to charge the retort hoppers every two hours and generally maintain smooth working of the plant. It was noted that some pokering down the retort tubes was required and that the internal oil vapour draw-off lines had to be cleaned at intervals of about 20 days.

The H.G. or Rockesholm Retort

There is only one bench of 72 of this type at Kvarntorp and this is supplied with shale of 27 to 80 mm. size.

It is a much modified Scottish type retort, the originators of these modifications being Messrs. Hultman & Gustafsson. Each retort is an externally heated tube 0.8 m. (2 ft.) in diameter and 9 m. (28 ft.6 in.) high.

The lower firebrick portion is 3 m. long (9'9") built of special curved tongued and grooved tiles, 12" x 12" and 3" thick. These tiles are made in Sweden. A cross section of a bench of H.G. retorts is shown in Fig. 12.

The upper metal portion of the retort is 6 m. long (19'6") and is made up in 3 sections with spigot and faucet type joints. The two topmost sections are of cast iron about 25 mm. thick (1") and the third section is an alloy.

Each retort is in a cell in which gas burns upwards without the aid of transverse flues.

The vapour offlet is attached to the retort some distance below the base of the shale hopper, which is itself closed by a moveable lid and sealed by steam. Each hopper is common to two retorts but is fitted with two lids.

Near the retort base, superheated steam is admitted to aid distillation, the steam being superheated in a coil placed in the waste gas flue from each group of 4 retorts. Each set of 4 retorts has a separate steel chimney.

The extraction is basically of the Pumpherston type with fixed table and rotating wiper arm, but instead of being ratchet operated, each extractor shaft is driven continuously by a wrom gear which derives its power from a rotating shaft running the whole length of the bench.

The de-oiled shale is discharged through a simple dry door into large cars containing about 2 tons of residue. These are moved by endless rope haulage direct from under the benches to the "coke" furnaces where the free carbon is burned out.

As would be expected there was a great deal of black dust around the base of these retorts and the operators were very dirty.

With a raw shale of 27 to 80 mm. size (1.1/8' -3") a throughput of 900 tons per day is obtained from 72 retorts, equivalent to 12 1/2 metric tons per retort per day, or 12 imp. tons per day.

The steam admitted to the retorts amounts to one-third of a ton per ton of shale, but despite this the make of ammonium sulphate is only 3 Kg. per ton (6 1/2 lbs. per ton).

The de-oiled shale leaving the retorts is at a temperature of about 400°C. (750°F.) and contains 10/11% of free carbon. Originally this was dumped, but the nuisance created by the burning residue and the loss of heat therefrom prompted the development of "coke" burning furnaces which will be described later.

The yield of oil from the H.G. retorts is stated to be 100% of the Fischer assay, i.e. about 12 imp. gls. per ton of 2240 lbs.

It is not the intention of the Swedish Shale Oil Coy. to build more H.G. retorts. Fig. 13 shows the H.G. bench at Kvarntorp.

<u>The I.M. or Tunnel Kiln Retort</u>

There are two tunnel kiln retorts at Kvarntorp, each handling about 450 tons of shale per day. These retorts are similar to those in use in Estonia and consist essentially of a circular insulated steel tunnel, 60 m. (197 feet) long and 3 1/2 m. (11 1/2 feet) in diam., fitted with pneumatically operated lock gates at either end. In the tunnel, perforated cars of shale, containing about 2.8 tons of shale each, are passed slowly through, one car of de-oiled shale being removed

to permit a newly charged car to enter at the other end. Each retort accommodates 24 cars at a time. The general principle of the retort is illustrated in Fig. 14.

Heat for retorting is generated in three oil and gas fired furnaces situated at intervals along the outside of the tunnel. Hot combustion gases pass through 3" tubes running longitudinally in the tunnel in the space not taken up by the cars of shale. The heating tubes are arranged in three sections and are operated at increasing temperatures, viz. 350°C., 450°C. and 55°°C. (660°F., 840°F. and 1020°F.).

The distillation gases and vapours are circulated transversely in the tunnel by 21 electrically driven fans with a total loading of 300 KW. The heat in the combustion gas tubes is thus transferred to the shale in the cars. Part of the oil vapours is continuously drawn off and condensed. The products of combustion from the three furnaces are passed through a waste heat boiler (La Mont tubular) before escaping to atmosphere via a tall chimney.

The I.M. retort gives a good oil yield and gas of high quality, but it is not in favour in Sweden for the following reasons:

(1) It is not self-supporting thermally and acid tar is burned in the furnaces along with fuel gas.

(2) Owing to the cracking of the oil vapours in the tunnel, the equipment becomes covered with coke and a shut-down for decoking is necessary every three weeks.

(3) The free carbon content is the shale is not utilised and separate "coke" burning furnaces are necessary.

(4) The retort requires a lot of attention mechanically.

Of the two I.M. retorts at Kvarntorp, the older one has perforated flat cars in which the hot gases pass through the shale in an upward direction. In the newer and preferred retort the cars are vertical and present a layer of shale about 1/2 m. thick (1.6 ft.) to the hot distilling gases.

THE LJUNGSTROM METHOD

The Ljungstrom Method of oil recovery is based on electrothermal heating of the shale underground and may be considered at this point in the report. The principle was invented by Dr. Fredrick Ljungstrom in 1940 and depends for its success on two main provisions:

(a) Cheap electric power
(b) A gas-tight head or cap above the shale.

The first applies in Sweden, and with the extension of the Kvarntorp modification of the Bergh retorting process, surplus electric power will be available in the future from the Works itself.

The second requisite is also found at Kvarntorp where the shale bed in an extension of the present opencast mining operations has a cover of limestone 5 to 7 m. thick (19 1/2-23 ft.) as shown in Fig. 2. Rotary drilling machines are used to drill holes 5.6 cms. in diam. (2.2") from 26 to 28 m. (80 to 92 ft.) down into the shale strata. The drills pass through about 2 m. of soil (6 1/2 ft.), 6 to 7 m. of lime-stone (19 1/2 to 23 ft.) and 17 m. of oil shale (56 ft.). The holes thus extend to the bottom of the oil shale seam. Immediately after drilling, the holes are lined with 4.8 cms. (1.9") diam. steel tubes. The six heating holes of each unit, which are arranged in a hexagonal pattern 2.2 m. (7 ft.) apart, are lined to the bottom, whereas the centre gas offtake tube is lined to the top of the shale only. The casing tube for each heating hole is made and inserted in a single length (26 m. or 83 ft.) by means of a special lattice steel mast.

The casing is closed at its lower end and the annular space between the tube and the wall of the hole is filled with a slurry of fine sand and water which, when dried out, facilitates heat transfer. In each heating hole an electric heater of 10 KW. loading is placed. These heaters consist of corrugated chrome steel elements fitted into steel tubular cases and insulated with quartz sand. A soft iron connection carries the current to the heater and the casing acts as a return lead. High voltage current is stepped down in pressure in two stages to 152 volts. The second step is performed by mobile field transformers. The amount of energy supplied to the field varies according to the availability and is normally from 20,000 to 24,000 Kw.

When heating is started in a new area for the

first time, from 4 to 5 months elapse before oil vapours appear at the surface. At regular intervals new heating holes are started and old ones abandoned, but the average heating time for any area is about five months. During the first three months the shale bed temperatures reaches about 280°C. (550°F.) and during the following two months the temperature is raised about 400°C (760°F.). During this period and a short time thereafter the oil vapours and gas find their way between the laminations of the shale to the collecting holes and hence to the condensers under their own pressure.

The heat wave produced by shutting down spent areas and heating new ones passes through the shale bed at the rate of about 140 m. (470 feet) per annum.

The width of the area being heated is 180 m. (600 feet) and about 2,000 heating elements are in use at one time.

The central oil vapour holes in ach hexagon are connected by a network of pipes to two main 8" diam. headers. The gases leave the ground at about 300°C. (570°F.) and pass through air cooled condensers to recover the oil, which is run to field receiving tanks. These condensers are force-cooled by a battery of electrically driven fans.

Fig. 15 shows the final stepdown field transformers and some of the vapour collecting pipes, while Fig. 16 shows the vapour mains and the electrically driven fans and condensers, Disused heating pipes may be seen in the foreground.

The yield of oil from the Ljunstrom system is approximately 40.8 U.S. barrels (6.5 cu. metres or 1431 Imp. gls.) per hexagon. From 5 to 6 units of electricity are consumed per litre of oil produced (22.6 - 27.2 units per imp. gall.).

A field area of 25,000 sq. metres (270,000 sp. ft.) corresponding to 875,000 tons of shale (equiv. to 2397 tons/day) is normally worked each year. The efficiency of recovery is equivalent to about 60% of the Fischer assay. The crude oil produced by the Ljungstrom method is yellow to green in colour, but it rapidly darkens. It is more saturated than oil from the retorting processes and has a gasoline content of about 52% by vol.

The water which accompanies the oil contains 8 grs. of Ammonia (NH_3) per litre, equivalent to 0.62

lb. of ammonium sulphate per ton of shale.

The incondensible gas from the Ljungstrom field has the following analysis:

Gas	Crude % by vol.	Sulphur-free % by vol.
CO_2	5.0	6.7
H_2S	25.0	-
CO	0.5	0.7
O_2	0.0	0.0
N_2	2.0	2.7
H_2	18.0	24.0
C_nH_{2n}	4.0	5.3
C_nH_n	45.5	60.6

Gross Heating Value: 9,100 K. cals./cu.m.
1,020 B.T.U./cu.ft.

The Ljungstrom area has, however, not been working for two years, but it is intended to restart it in 1952 once all the Bergh retorts are converted to the Kvarntorp modification and surplus electric power is available.

CHEMICAL ANALYSIS OF SHALE, HEAT CONTENT, ETC.

The raw shale from Kvarntorp and the shale ash have the following compositions:

Raw Shale

	% wt.
C	18.0
H	2.0
S	6.3
Moisture	1.9
Ash	71.8

Shale Ash

	% wt.
SiO_2	60.7
Fe_2O_3	11.2
Al_2O_3	22.5
K_2O	5.1
Na_2O	0.5
CaO	-

The Swedish shale has an average calorific value of 2050 k. Cals per Kg. (3690 B.T.U./lb.) and gives 5.5% wt. oil yield on Fischer assay. The distillation residue from the Swedish shale has a calorific value of 1100 K. Cals/kg. (1980 B.T.U./lb.).

HEAT BALANCE IN THE SHALE RETORTS AND LJUNGSTROM PROCESS IN SWEDEN

The following table shows the heat balance in the four processes used at Kvarntorp (4).

Line (C) gives the heat value of oil, gas, sulphur and steam generated.

Line (D) gives the heat value of fuel, steam and electricity used in retorting.

Line (E) gives the net heat available from the process and saleable as oil, gas, sulphur, steam, etc.

From these figures the efficiency of retorting has been worked out and is shown below the table. The overall efficiency varies from 15.85% in the case of the Ljungstrom process to 50.73% with the Kvarntorp retorts.

HEAT BALANCE

KILO CALORIES PER KILOGRAM OF SHALE

	Product	Calorific Value of Shale – 2050 K. Cal/kg				
(A)		Ljungstrom K.Cal/kg. shale	I.M. Oven K.Cal./kg shale	H.G. Oven K.Cal/kg shale	Bergh Oven K.Cal/kg shale	Improved Bergh Oven K.Cal/kg shale
	Crude Oil	250	420	410	390	390
	Gasoline	30	50	70	45	45
	Gasol (L.P.G.)	55	85	105	80	80
	Combustible Non-Condens. gas	100	105	185	115	115
	H_2S	40	55	70	55	55
	High Press. Steam					
	Excl. Coke Burning	–	20	–	–	–
(B)	Incl. Coke Burning	–	400	400	400	460
	Total available Heat in Products					
	Excl. Coke Burning	–	735	840	–	–
(C)	Incl. Coke Burning	475	1,135	1,240	1,085	1,145
	Consumption of Fuel for Retorting					
	Fuel	–	360	300	–	–
	Low Press. Steam	–	40	155	235	95
	Electric Energy	150	15	5	10	10
(D)	*Total heat required for Retorting*	150	415	460	245	105
	Surplus Heat available for sale as Oil, Sulphur, Steam, etc.					
	Excl. Coke Burning	–	320	380	–	–
C-D (E)	Incl. Coke Burning	325	720	780	840	1,040

HEAT BALANCE:

BRITISH THERMAL UNITS PER POUND OF SHALE

	Product	Calorific Value of Shale – 3690 B.T.U./lb.				
(A)		Ljungstrom B.T.U./lb. Shale	I.M. Oven B.T.U./lb. Shale	H.G. Oven B.T.U./lb. Shale	Bergh Oven B.T.U./lb. Shale	Improved Bergh Oven B.T.U./lb Shale
	Crude Oil	450	756	738	702	702
	Gasoline	54	90	126	81	81
	Gasol (L.P.G.)	99	153	189	144	144
	Combustible Non-Condens. Gas	180	189	333	207	207
	H_2S	72	99	126	99	99
	High Press. Steam					
	Excl. Coke Burning	–	36	–	–	–
(B)	Incl. Coke Burning	–	720	720	720	828
	Total Available Heat in Products					
	Excl. Coke Burning	–	1,323	1,512	–	–
(C)	Incl. Coke Burning	855	2,043	2,232	1,953	2,061
	Consumption of Fuel for Retorting					
	Fuel	–	648	540	–	–
	Low Press. Steam	–	72	279	423	171
	Electric Energy	270	27	9	18	18
(D)	*Total Heat required for Retorting*	270	747	828	441	189
	Surplus Heat available for Sale as Oil Sulphur, Steam etc.					
	Excl. Coke Burning	–	576	684	–	–
C-D (E)	Incl. Coke Burning	585	1,296	1,404	1,512	1,872

EFFICIENCY OF RETORTING

Derived from figures in foregoing tables

	Ljungstrom	I.M. Oven	H.G.Oven	Bergh Oven	Improved Bergh Oven
$\frac{C}{A} \times 100$ Thermal efficiency of retorting and coke burning (Fuel, Steam and Electricity for retorting not included).	23.17%	55.37%	60.49%	52.93%	55.85%
$\frac{E}{A} \times 100$ Thermal efficiency as above, but taking into account Steam and Power used in retorting.	15.85%	35.12%	38.05%	40.98%	50.73%

RECOVERY OF HEAT IN DE-OILED SHALE (SHALE COKE)

The de-oiled shale from the H.G. and I.M. retorts contains from 10 to 12% of free carbon and at one time this was dumped. This material, however, is pyrophoric and gives off objectionable vapours on burning. It became necessary, therefore, to burn this "shale coke" and desirable to recover the heat available in it. The Bergh and later the Kvarntorp retorts made use of the shale coke in their own furnaces, so it was decided to build an experimental coke burning plant which would recover the heat in the H.G. and I.M. residues. The grate load on the old Bergh retorts was of the order of 100 Kg. per sq. m. per hour (20 lbs./sq. ft./hour) and it was hoped to exceed greatly this rate in the external coke furnaces, as something like 1600/1700 tons of residue had to be handled per day. Because of the low fusing temperature of the ash also, the temperature of the furnace had to be kept under 950°C (1740°F.). It was considered that if suitably designed, heat absorbing steam generating elements were disposed in the burning coke bed, it would be possible to keep the temperature within the desired limits and still maintain a high CO_2 content in the flue gases. The first pilot plant for coke burning comprised a firebrick shaft 3.1/2 m. (11'6") high and about 1 m. square (3'3"). A cross section of this furnace is shown in Fig. 17.

The heat absorbing surfaces were La Mont tubes in the form of hairpin coils, 25 mm. (1") inside diam., arranged vertically and at short centres over the whole area of the shaft and extending for the full height. The tubes were thus embedded in the flowing coke and effectively controlled the bed temperature. A grate loading of 700 Kg. per sq. m. per hour (144 lbs./sq. ft./hour) was possible with a flue gas CO_2 content of 10-12%.

As a result of these tests coke burning units were planned to handle the whole of the residue from the H.G. and I.M. retorts and the first were started in 1946.

Figs. 18 and 19 show in cross section the arrangement of the coke furnaces presently in use. The de-oiled shale at about 400°C. (750°F.) is brought to the furnaces in 2-ton wagons and dumped into the charging hoppers, which feed the furnaces directly. The bottom of each cell or furnace is fitted with a water sealed door with a water seal depth of 100 mm. (3.9 in. w.g.). The air pressure is normally 50 mm. w.g. (2.0 ins. w.g.).

The shaft bottom consists of 5 cast iron toothed discharge rollers which also act as crushers for the ash.

The La Mont hairpin tubes in the furnace cells are fed with treated water from a central station serving the 40 shafts in the works. Air for combustion is led through the base structure which supports the discharge roller bearings.

Waste gases from each group of 8 furnaces are led through a waste heat boiler (La Mont tubular pattern) in which the gases are cooled to approximately 275°C (525°F).

As first erected, all the coke burning furnaces generated steam at 30 ats. pressure (450 p.s.i. - 31.5 Kg. per sq. cm.) but as it was required to superheat the steam to 400°C (750°F), tests were made to find if this could be done in a group of coke burning furnaces without experiencing sintering troubles. Following a succ ssful trial, 8 of the 40 shafts are now used to superheat steam to 450°C (842°F) using alloy tubes containing 13% cheomium.

Fig. 20 illustrates a setting of 3 units of 8 coke burning furnaces, i.e. 24 in all.

In the 40 furnaces, about 1,200 tons of superheated steam are generated per day.

The combustion efficiency of these furnaces is given as 60%. Because of the local cooling effect of the tubes, combustion is not complete where the mineral contacts the tube wall as compared with midway between the tubes. The carbon content of the ash leaving the furnaces is therefore from 4 to 5% as compared with 10-12% in the hot coke entering at the top.

The Swedish engineers admit that the transportation and burning of the shale coke in separate furnaces is a dirty operation involving much plant and handling of material. Ultimately they hope to adopt the Kvarntorp retort as the only oil producing unit (other than the Ljungstrom process) and abandon the H.G. and I.M. retorts with their separate shale burning furnaces.

REFINING OF THE SHALE OIL

The Oil from Kvarntorp shale is highly unsaturated and aromatic, and contains no wax. The oil from the three retorting processes is more unsaturated than that from the Ljungstrom heating in situ process and

contains less gasoline and more sulphur.

Typical analyses of the two types of oil are as follows:

	Retort Oil	Ljungstrom Oil
Sp. Gr. at 20°C.	.980	.920
Sulphur, % wt.	1.7	1.2
Viscosity (c.s.) at 20°C (68°F.)	22	1.5
A.S.T.M. Distillation		
I.B.P.	80°C	45°C
5% dist. at	140 "	70 "
10% " "	160 "	90 "
20% " "	190 "	125 "
30% " "	225 "	155 "
40% " "	265 "	180 "
50% " "	300 "	210 "
60% " "	-	245 "
70% " "	-	270 "
Crude Gasoline 170°C	15% vol.	35% vol.
Kerosene, 170-230°C.	15% vol.	20% vol.

Type analyses of the oils from the three retorting processes employed at Kvarntorp show them to be almost identical in comprising 55% olefines, 25% of paraffins, 10% of naphthenes and 10% of aromatics. The Ljungstrom oil on the other hand contains 40% of olefines and 40% of paraffins, the aromatics and naphthenes remaining at 10% each.

Thiophene and its homologenes comprise 80 to 90% of the gasoline sulphur compounds if the lowest fractions are excepted and in which mercaptans and carbon disulphide are predominant.

The phenol content of the crude gasoline is 2 to 3 kg. per cu. metre (0.02/0.03 lb./gall. or 0.26% wt.)

The residue left after removal of gasoline is rich in aromatics and olefines and low in paraffins. This applies particularly to the retort oils and explains the poor quality of diesel oils made experimentally from Swedish shale oil.

When the Ljungstrom field is operating, the oil from it is collected and refined separately.

From all the crudes, only three products are at present manufactured, viz. Gasoline, Power Kerosene (T.V.O.) and Fuel Oil.

The Gasoline varies in volatility according to the season, and the quantity of Power Kerosene made varies according to demand. At present only about 5% of the crude appears as Power Kerosine. The bulk of the crude oil (55 to 83% according to the source) is sold as Fuel Oil, the product for which the industry was started during the second world war.

REFINING EQUIPMENT

This consists of a crude topping unit, continuous acid and soda washery, re-run unit and plumbite treaters. There is also a small tank farm adjacent to the refinery on slightly elevated ground.

TOPPING OF CRUDE OIL

Distillation is carried out by steam heat only in a plant having a capacity of 275 cu. m./day (60,000 gallons). The crude is passed through a tubular preheater against residue from the fractionator before being raised to 180°C. (266°F) in a vertical tubular heater supplied with H.P. steam. The heated crude is flashed to a 12 plate column into the base of which is injected open steam. A crude gasoline is taken overhead with an end point of 200°C and amounting to about 17% on the charge to the still. The residue of fuel oil has a flash point of about 150°F. These figures apply to retort crude oil, but when Ljungstrom oil is being run, a 45% distillate is taken off to 200°C. end point as this crude is much lighter. The residue from the subsequent re-running of the treated gasoline is blended with the crude residue to give fuel oils of two grades as shown in Table 1.

TREATMENT OF CRUDE GASOLINE

The analyses of crude gasolines from retort a and Ljungstrom oils are shown in Table 2 along with that of scrubber naphtha. The crude gasoline and scrubber naphtha are mixed as available and treated together before re-running. (Scrubber naphtha is the bottoms from the L.P.G. plant after taking off C_3 and C_4 fractions). The crude gasoline treating plant has a capacity of 150 cu.m. per day (33,000 galls.) It is a five stage unit consisting of centrifugal pumps, orifice mixers, centrifugal separators (Alfa Laval) and small surge tanks. The time of contact between gasoline and acid is about 40 secs. and at each acid stage the gasoline is cooled to 5°C. (41°F.). The sulphur content of the treated spirit may not exceed 0.2% and to maintain this figure an acid treatment of 5.4% by vol. (12.5% wt.) is given the retort crude oil gasoline and 4.2% vol. (10.0% wt.) for the Ljungstrom gasoline.

Treatment losses are 13% and 10% respectively, but polymer oil is recovered by dilution of the acid tar, which reduces the actual oil loss to 5%. This polymer oil is used as a fuel at the tunnel kiln retorts.

The five treatment stages are as follows:-

(1) A preliminary treatment with 12% conc. caustic soda from the neutralisation stage. This phenolated caustic is ultimately neutralised with recovered acid from the hydrolysis of tar, to release the phenols which are used as fuel. Otherwise recovered acid is not made use of at Kvarntorp.

(2) After cooling to 5°C a treatment is given with acid tar from the 3rd and 4th stage treatments. The tar from this treatment is washed with water for the recovery of polymer oil, which is used as fuel.

(3) After cooling to 5°C, a treatment with fresh acid (66°Be - 1.84 S.G.) is given.

(4) As in (3).

(5) A final treatment with fresh 12% caustic soda.

The centrifugal treatment pumps are situated in a row on the ground floor of the treating house. The pumps are driven by electric motors which are on the other side of the wall of the building from the pumps. The orifice mixers are in the form of small towers outside the house and the centrifugal separators are on an upper floor of the same house, driven by motors on the other side of the wall.

The surge tanks are very small in size (about 2.2 cu. m. or 500 galls.) and are situated outside also. Tar is run from them at intervals.

The treating plant is illustrated in Figure 21.

REDISTILLATION OF TREATED GASOLINE

This is carried out by steam heat in one atmospheric and two vacuum stages, taking off light gasoline, heavy gasoline and power kerosene (T.V.O.) and leaving a residue which is returned to fuel oil.

The purpose of the vacuum distillation is to keep the temperature so low (under 130°C) as to

minimise the breakdown of di-alkyl sulphuric acids with the release of sulphur dioxide gas and coking of preheater tubes. Actually some SO_2 is generated and corrosion on the re-run unit is troublesome. For this reason the condensers on the second and third stages are made of stainless steel, and a mixture of ammonia gas and soda is injected into the first stage feed line.

The feed is heated by closed steam at a pressure of 10 kg./sq. cm. (142 p.s.i.) and in the last stage the pressure of the vapours in the column is approximately 60 mm. mercury.

FINISHING TREATMENTS

The reason for separating light and heavy gasolines is that the light gasoline must be freed of carbon disulphide, which it contains, and which is unaffected by its passage through the acid treating plant. This is done by washing the light gasoline with a 15% solution of caustic soda in Methanol, which, besides removing the carbon disulphide as sodium methyl xanthate, also acts as solutizer solution and removes low boiling mercaptans. The chemistry of the removal of carbon disulphide is shown in the following equation:-

$$S=C=S + NaOCH_3 \rightleftharpoons S=C\left\langle\begin{matrix} S-Na \\ OCH_3 \end{matrix}\right.$$

Carbon Disulph. + Sod. Methylate = Sodium Methyl Xanthate.

As the reaction is reversible, carbon disulphide is driven off on heating and the reagent is available for re-use. This heating is done in a column with open steam and as the products of the steaming are carbon disulphide, mercaptans and methanol, column conditions are so arranged that the sulphur compounds are taken off overhead and the methanol as a tray cut.

Some of the methanol dissolves in the gasoline and this is washed out with water, the dilute alcohol being then rectified with 85% recovery.

The total consumption of methanol is given as 0.15% vol. of the crude gasoline treated.

The gasoline so treated is sweet and is ready for blending with the heavy gasoline which is sweetened by a different process.

The heavy gasoline and the kerosene are separately sweetened in continuous plumbite plants. The used plumbite solution befor regeneration with air is centrifuged in a special machine which separates entrained gasoline or kerosene and also divides the plumbite into two streams. One contains practically all the lead sulphide in suspension and the other contains practically no lead. Some of the lead-free stream is replaced continuously by fresh plumbite solution.

Light and heavy gasolines are produced in the ratio 2:3, and these are mixed to give a motor fuel having particulars as shown in Table 3. The octane number of the gasoline is 70/72 MM. It is claimed that the addition of 25% of benzol raises the engine test to 80/82 MM. The lead response is poor, the addition of 0.06% of T.E.L. (2.72 cc. per I.G.) increasing the octane rating by only 3 to 5 numbers, i.e. to 74/75.

Two grades of gasoline are marketed, the Regular grade containing no lead and having an octane rating of 70/72, and the Premium grade containing 0.06% T.E.L. (2.72 mg./I.G.) and some benzol or alcohol and having an octane rating of 75/78.

Table 4 is a flow diagram of the refining scheme employed at Kvarntorp, and this is also shown in diagrammatic form in Figure 22.

DESPATCH OF PRODUCTS

This is done both by road and rail. Figure 23 illustrates the second of these methods. Gasoline is largely transported by road in attractive six-wheeled tank wagons holding about 12,000 litres (2500/300 gallons.)

TREATMENT OF RETORT GASES

The vapours from each retorting unit are passed through condensing equipment attached to each unit. Because of the virtual absence of steam in the vapours, the condensing plant is small. Some units employ water cooled tubular condensers and in others the vapours are sprayed with water in small towers. The gases from the retort condensers and from the air cooled condensers at the Ljungstrom site are collected and passed forward to the sulphur recovery units where the H_2S in the gases is scrubbed out and converted into elemental sulphur.

The H_2S free gas passes to the L.P.G. (Liquified Petroleum Gas) plant for removal of C_3 and C_4 hydrocarbons. Exit gas from the L.P.G. plant may be used as fuel at steam boilers, lime plant or at the I.M. and H.G. retorts. For a time some was piped to the adjacent

town of Orebro and it is intended soon to use some of it in the production of synthetic ammonia and nitric acid.

The bottoms from the debutaniser column at the L.P.G. plant has a boiling range of approximately 40 - 180°C. (See Table 2). The yield of this product, which is blended with crude gasoline, is 5-6 Kg. per ton of shale. (1.5-1.8 gallons per ton).

Analyses of the gases from the various retorts in use at Kvarntorp (and the Ljungstrom system) are shown in Table 5.

SULPHUR RECOVERY PLANT

This is an important feature of the process at Kvarntorp. The shale gas contains about 20% OF H_2S and the sulphur recovery amounts to about 14,000 tons per annum at present, with a probable future recovery of 20,000 tons. On being questioned as to the source of the H_2S in the gas, Prof. Schjanberg said that while a little came from the breakdown of organic sulphur compounds, most of it was derived from pyrites in the shale. Roasting of pyrites in presence of carbon and in the virtual absence of air was stated to be responsible for the large H_2S production. The sulphur content of Narke shale is 6 1/2/7%.

The H_2S is removed from the gas by the Alcazide process, using a synthetic base, Potassium N dimethyl glycine or DIK Lye.

$$\left.\begin{matrix} CH_3 \\ CH_3 \end{matrix}\right\rangle N - CH_2 \cdot\cdot\ COOK$$

This lye absorbs H_2S preferentially to CO_2. The H_2S is released on heating the H_2S-bearing lye, giving a gas containing over 90% H_2S. A portion of the H_2S us burned in a steam boiler to give SO_2 which is then mixed with H_2S in the volume ratio 1:2 and passed upwards through two catalyst cases in series, the catalyst being activated bauxite.

Molten sulphur of over 99% purity flows from these catalyst cases and is cooled in two ways. In the first method the sulphur is run into large brick lined pits with one removable end for cooling and subsequent removal in the solid state. The solid sulphur is either sold in lump form or is ground to powder. In the second

method, the molten sulphur is pumped to the top of a tall steel tower built on top of a concrete silo. The molten sulphur is sprayed down this tower against an ascending current of cold air, the resultant granular sulphur falling directly into the silo for storage or removal from the base as required.

There are three BAMAG sulphur recovery units at Kvarntorp each capable of treating 3,000 cu. m. (105,950 cu.ft.) of gas per hour. Two of these are normally in use. A larger plant is in course of erection, capable of handling 6,000 cu.m. (211,900 cu. ft.) of gas per hour.

The average price for flowers of sulphur in Sweden is 400 Sw.Kr. per ton and for crude lump sulphur 260 Sw.Kr. per ton.

Fig. 24 shows one of the sulphur recovery units.

LIQUEFIED PETROLEUM GAS PLANT

This is a modern unit, built by Foster Wheeler two or three years ago.

The gas is scrubbed with a heavy spirit fraction at 18 atm. pressure (265 p.s.i.) after being compressed and freed from moisture by passing through activated alumina. The gas compressors are motor driven, three-stage units, made by Ingersoll-Rand. The first stage cylinder is vertical and the second and third stage cylinders are in line horizontally. There are four of these units, each capable of handling 2,500 cu.m./hour. (88,400 cu.ft./hour).

The main columns in the L.P.G. plant are:

1) The ansorber in which the dried gas is scrubbed with a heavy naphtha.

2) The still-overhead from which is taken the C_3/C4 fraction from the loaded naphtha.

3) The depropaniser - overhead from which is taken the C_3 fraction from the product from (2).

4) The debutaniser - overhead from which is taken the C4 fraction from the product from (2). The residue from (4) is scrubber naphtha.

The C_3 and C_4 fractions are washed with soda in mechanically stirred (Holley-Mott type) washers before

passing to storage.

The L.P.G. is stored in 16 horizontal cylinders (2 m. diam. and 12 m. long). These have storage capacity for 700/800 tons of liquid. The dip gauges are of the float type. Sight glasses are not used.

The incondensible gas from the still contains traces of hydrogen sulphide as well as carbonyl sulphide (COS) and carbon disulphide (CS_2).

The gas passes through a catalytic unit which converts these carbon sulphides to H_2S and the resultant H_2S is removed by scrubbing in a Girbotol plant with di-ethanolamine.

DESPATCH OF L.P.G.

Gases are filled into cylinders varying in capacity from about 10 to 30 Kg. (20 to 60 lbs.) For use at engineering works and for village cooking requirements, a few horizontal cylinders of 1,100 kg. (2,500 lbs.) capacity are also used, these being lifted on to and transported by motor lorry. Kvarntorp L.P.G. is sold in Sweden under the trade name of "Gasol". The interior of the filling shed is shown in Fig. 25.

PRODUCTS OTHER THAN OIL MANUFACTURED AT KVARNTORP

By far the most important of these is sulphur, the production of which has already been described.

Another product being made in quantity is lime. The hand-picked limestone from the shale conveyor belts is burned in one or more of three lime kilns. These are steel shafts, brick lined, and fired with shale gas. The quicklime made in these kilns is of poor quality and is principally used for agricultural purposes. The lime is sold in lump and powder form. It was noted that the chimney from each kiln was smoking continuously, thus indicating the presence of oil shale in the limestone. The annual production of quick lime is about 45,000 tons.

Some ammonium sulphate is also made at Kvarntrop. Only the aqueous condensate from the H.G. (modified Scottish) retorts is used and the sulphate of ammonia yield is given as 3 kgs. (6 1/2 lbs) per ton of shale. The sulphate plant was not inspected, but a sample of the product shown was of poor quality and colour. It is understood that waste acid from an explosives factory is used in this plant.

PLANS FOR OTHER PRODUCTS

Although no non-hydrocarbon by-products other than sulphur and lime are being produced on a large scale, experimental work has been carried out in a number of directions. Something of these plans was outlined by Professor Schjanberg.

Using the local lime and spent shale, it has been found possible to produce good quality sand/lime type bricks, and a small experimental brickwork is in operation at Kvarntorp. The autoclave conditions were given as 80°C. for 24 hours and the crushing strength of the bricks as 250 Kg. per sq.cm. (3,570 lbs./sq.in.).

Some work has also been done on the manufacture of insulating bricks (Gas Betong) from spent shale and lime, using powdered aluminium to generate gas and so produce porosity.

In addition to lump, granulated and powdered sulphur, some sodium sulphide solution has been produced for use as a depilatory in the leather industry. As much as 500 tons per annum has been sold, but at present production has stopped until some work has been done on eliminating the mercaptan content of the sulphide.

From the I.M. oven retorts some pitch is collected, and this, although brittle, has been used experimentally in making roofing paper.

There has been some sale for shale fuel oil as a wood impregnating oil. Toxic and mycological tests have shown that the shale oil can compete with creosote, particularly if the fuel oil is improved by the addition of 4 to 5% of phenols extracted from gasoline.

The "rest gas" or permanent gas remaining after desulphurising and removing liquefiable hydrocarbons, has a calorific value of 3,000 k. cals./cu. m. (338 B.T.U./cu.ft.). The composition of this gas is approximately:

CO_2	2%
CO	1%
N_2	45%
H_2	26%
Hydrocarbons	26%

A considerable amount of pilot plant work appears to have been done on the preparation of syn-

thetic ammonia and nitric acid from this gas, and it is planned to erect a plant for commercial production of anhydrous ammonia and of calcium nitrate.

The route proposed is to convert the hydrocarbon constituents (methane and ethane) into hydrogen and carbon monoxide by cracking in the presence of steam, followed by a second inter-action with steam to convert the carbon monoxide to carbon dioxide and more hydrogen. The CO_2 is removed by high pressure solution in water followed by copper removal of unreacted CO. Finally, the mixture of hydrogen and nitrogen in the ratio 3:1 is converted into ammonia over a catalyst at 325 atm. pressure (4,500/5,000 p.s.i.). The nitrogen constituent of the shale gas as used in this reaction and separation of nitrogen from atmospheric air is unnecessary.

It is planned to convert most of the synthetic ammonia to nitric acid for the production of calcium nitrate fertiliser, utilising the abundant supplies of impure limestone available in the shale.

CONTROL AND RESEARCH LABORATORY

These departments are housed in separate sections of the same building. Approximately 20 qualified chemists and 20 assistants are employed altogether.

Problems which are being or recently have been examined are:

1) Catalytic desulphurisation and refining of shale gasoline as an alternative to the present method of treatment with acid. Hydrogen produced from methane has been used catalytically to convert sulphur in the gasoline into H_2S and to saturate the olefinic hydrocarbon constituents.

2) Cracking of shale fuel oil to yield a greater diversity of products.

3) The separation of uranium concentrates from spent shale.

4) The manufacture of building bricks and also insulating bricks using aluminium powder as a gas generator.

5) The recovery of potash and alumina from shale ash by reaction with lime to form calcium-aluminium silicates and caustic

potash. After pilot trials the process was abandoned.

6) The production of alcohols, ethers and ketones from the hydrocarbons of shale gas. This work was stated by Prof. Schjanberg to have reached a semi-commercial scale.

7) Investigation into the nature of the sulphur compounds in Swedish shale oil.

8) The production of Transformer Oil (an important commodity in such an electrified country). This has been done by: (a) the furfural refining of a suitable distillate from fuel oil. This process can only be applied to the Ljungstrom oil as the yield from retort oil is very small; (b) hydrogenation of a distillate oil at 200 atm. pressure and 375°C. followed by an acid treatment. The second process can be applied to either retort or Ljungstrom oils and the oils obtained by either of the two methods are stated to be of good quality.

9) Hydrogenation of heavy oil to give, after fractionation, gasoline and diesel oil. These are stated to be of poor quality, viz. the gasoline has an octane rating of 66 and the diesel oil has a cetane number of only 30. By furfural extraction of the hydrogenated diesel oil, a product of 60 cetane number can be obtained.

10) Thermal coking of heavy oil has been investigated, but results are not promising as preliminary yields are: 25% gas, 25% gasoline and 50% coke. The gas oil, however, because of its aromatic nature, is suitable for the manufacture of carbon black and of such oxidation products as maleic and phthalic acids.

11) Some work has been done on the nature of the "kerogen" in Swedish shale oil.

12) Direct hygrogenation of Swedish shale has been attempted using a temperature of 400°C. and 20 atm. pressure (750°F. and 300 p.s.i.). An increased yield of oil was obtained (as cf. retorting), but the oil obtained was heavy.

Most of these points of investigation are summarised in the diagram, Fig. 26.

DISPOSAL OF SPENT SHALE

Most of the spend shale is returned to the quarry and it is intended to treat all residue in this way in the near future.

A prominent feature of the works at Kvarntorp, however, is an irregularly shaped "bing" of spent shale stated to contain about 10 million tons. Shale residue is still being tipped on this heap by a method involving conveyor belts. The shale is disposed of from one head only which at present is about 300 feet high and is reached by a long straight inclined road. At the bottom of the heap is a steel hopper into which spent shale is tipped and which feeds a conveyor belt running up the hill to about two-thirds of its height. This belt also is elevated on steelwork about 2 metres (6'6") above the road level. For the remaining one-third of the way up the heap a second belt carried the shale to the tipping head. This second belt is half as long as the whole road from the bottom to the top so that part of it runs under the first belt. As the head goes out, the second belt is moved bodily upwards and owing to part of it being under the fixed belt it is still possible to tip as before. There is a small hopper at the upper end of the fixed belt which feeds the movable belt.

With this arrangement of belts alone the tipping head of the upper belt would soon become buried in shale, and an ingenious device is used to spread the shale as it comes off the end of the belt. This is a motor driven fast running spreader consisting of a boss with radial arms which throw the shale out from the head.

STEAM GENERATING EQUIPMENT AND POWER SUPPLY

The bulk of the steam is generated and superheated in the La Mont coils of the Kvarntorp retorts and in the separate shale burning furnaces.

There are two buildings, each containing two large steam drums on an upper floor. The level of water in each drum is maintained by 2 centrifugal feed pumps, one electrically driven and the other an emergency unit, steam driven. Water from each drum is pumped into a section of feed main which supplies water

to one Kvarntorp retort house or bench of shale burning furnaces. The water to each coil in each furnace is controlled by a shut-off valve and is metered to that coil by the usual La Mont orifice system. From each coil the emulsion of steam and water at 260°C. (500°F) passes into a return main which conveys it to the steam drums described above. Steam from the drums is conveyed to separate La Mont tubes of alloy insert d in separate Kvarntorp and shale burning furnaces, where it is superheated to 450°C. (840°F.). This superheated steam returns to the steam drum houses in which are also situated Ljungstrom steam turbines driving 3 phase alternators.

At present there are two 8,000 K.V.A. alternators in use, and a third, of 12,000 K.V.A., is in course of erection, giving a total capacity next year of 28,000 K.V.A.

These turbines take steam at 23 atm. pressure and 450°C. (335 p.s.i. and 840°F) and pass out at 10 and 2 1/2 atm. pressure (150 and 36 p.s.i.) as process steam.

The alternators generate 3 phase alternating current at 6,000 volts and there are distribution networks operating at 6,000 and 380 volts.

It is planned to consume power in the next few years as follows:

5,500 K.V.A. to general plants.

7,000 K.V.A. to ammonia and nitric acid plants.

14,000/24,000 K.V.A. to Ljungstrom field.

Steam may also be generated in three conventional steam boilers fired by gas or by fuel oil. Two of these are B.N.V. natural circulation water tube boilers of 12 tons of steam per hour (26,400 lbs./hour) capacity each. They are fitted with very large superheaters capable of handling the boiler output plus saturated steam from the old Bergh retorts. The third boiler is a La Mont forced circulation boiler of 21 tons/hour capacity (46,000 lbs./hour) with integral superheater for its own steam make. Only one boiler was working during the visit - a B.N.V. boiler, mainly used for superheating Bergh retort steam. Once the Bergh retorts are all converted to the Kvarntorp modification with La Mont steam generating and superheating tubes, these boilers will be used after a shutdown only.

WATER SUPPLY

Fresh water is pumped to the works from Lake Tisaren about 18 km. (11 miles) away, through a staved wooden main 50 cms (20") in diam.

Heated water is cooled in wooden cooling towers for re-use.

Water for steam raising purposes is treated in a lime-soda plant and a separate section of the control laboratory is devoted to boiler water testing.

EMPLOYEES

There are approximately 1,000 men employed at the Kvarntorp plant, excluding 100 who are required when the Ljungstrom field is in operation. It is expected that the synthetic ammonia and calcium nitrate plant will employ an additional 200 men.

WELFARE

There is a fire brigade with up-to-date equipment. A first aid station is constantly manned, and workmen's baths are provided, with two sets of clothes lockers, etc.

Hot meals may be obtained at the works canteen.

A group of very attractive two-storey wooden houses forms a village adjacent to the works. This village, built by the Company, has a community centre, a school, library, store, restaurant and playing field.

ECONOMICS

In a talk, Mr. Gejrot, Works Managing Director, gave the cost of the Swedish shale at the retorts (including interest on capital and a 13% amortisation charge) as 0.47 U.S. dollars per ton. The cost of Swedish crude shale oil was also given as 2.20 dollars per barrel (this cost including interest and amortisation as above).

Taking the rate of exchange as 2.80 U.S. dollars to the £ sterling, the costs of shale at retorts and oil as produced are as follows:

Oil share at retorts:	3/5d.per ton(2,240 lbs)
Crude Oil	5 1/2d.per gall. (imp.)

In a written statement Mr. Gejrot also gave the cost of oil production by the Kvarntorp retort for the year 1950 as Sw.Kr. 21.34 per cu.m. plus a depreciation charge of Sw.Kr. 56.0 per cu.m. At an exchange rate of Sw.Kr. 14,485 per £ sterling, these figures become 1.61d. per Imp. gallon plus 4.22d. per Imp.gall., giving a total cost of 5.83d. per gallon.

It should be noted that in calculating these costs the profits from by-products are credited to oil production before the direct production costs are calculated. In estimating these costs also the following rates of plant depreciation were taken into account: 5% for pipes, 3% for buildings, 25% for vehicles and 10% for general equipment. The average wage paid at Kvarntorp during 1950 was Sw.Kr. 3.10 per hour, quivalent to 4/3.36d. per hour.

For the first time the Company made a small profit in 1951. With the considerable expansion in output in 1952-53 it is expected that at present prices a considerable profit will be made.

The relation between output and profit is illustrated in charts 1 and 2. These show outputs, costs and profits in Phase I (1941) as compared with the corresponding figures for Phase 2 (1952-53) wh n present extensions are completed. In these charts the crude oil has been taken as worth Sw.Kr. 100 per ton equivalent to Sw.Kr. 65 per ton of coal. The equivalent sterling figures are £6.18. - and £4.9.9 per ton.

After deducting fuel used for retorting and electricity and steam for running the plant, the total surplus production of oil, gas and steam has been converted to the equivalent quantity of oil calculated on a heat value basis.

Chart I shows that the total production of oil or oil equivalents on this basis was 100,000 tons in 1941, and should be 214,000 tons in 1952-53. The proportion of gas and steam in the total is noticeably increased in the latter period.

Chart 2 compares production costs with revenues both for the 1941 phase and when the present extensions are completed in 1952 (Phase 2). As in Chart 1 the gas and steam are converted to the heat equivalent weights of oil and are presumed to be sold at the equivalent price: thus at Sw.Kr. 100 per ton, the revenues for the two phases are 10 million Crowns and 21.4 million Crowns respectively.

The effect of the manufacture of products other than oil, gas and steam is not taken into account. On these theoretical bases a deficit of Sw.Kr. 1.2 m. (£82,844) is shown for 1941, and a profit of Sw.Kr. 8.6 m. (£593,718) after reconstruction in 1952-53.

Swedish shale oil products do not enjoy any preferential treatment as regards customs or excise duty.

GENERAL IMPRESSIONS

Swedish oil shale from Narke province is low in oil yield and the oil is of poor quality and contains no wax or marketable diesel oil. These disadvantages are considerably offset by the high fixed carbon content of the shale which is made use of in steam and power generation and by the large yield of high grade sulphur.

The Kvarntorp retorts, although giving a comparatively low percentage yield of oil based on the Fischer assay, are peculiarly suited to the handling of a shale which is high in fixed carbon. The throughput of the Kvarntorp type of retort, however, is low and the units are multitudinous. It is possible that the shale might be more economically retorted in an internal combustion retort of large capacity which would liberate the oil and convert the fixed carbon into a gas which, although low in C.V., would be quite suited for use in gas turbines. An objection to this method, however, is that the gas would be so great in volume that the recovery of light spirit would be difficult, and also that some of the sulphur in the gas would appear as SO_2 and not as H_2S, which would render the recovery of sulphur much more uncertain.

The shale mining and handling methods appeared to be excellent and the crushing plant, though elaborate, was necessitated by the size of shale required at the Kvarntorp retorts.

The constant search for by-products of relatively high market calue was commendable, although some of the processes investigated were of academic rather than revenue producing interest.

About the whole industry there was an air of progress and initiative and the officials were obviously technical men of a very high order.

ACKNOWLEDGEMENTS

The officials of the Svenska Skifferolje Aktiebolget were courteous and helpful, answering questions very fully. We are very grateful to the Board of Directors for granting permission to inspect the operations and to the officials who spent so much time with us.

It was not permitted to take photographs in the mine or in the works and the illustrations attached to this report are taken from the official handbook of the Swedish Shale Oil Coy., and from a paper entitled "Recent Possibilities for Development by means of Modern Retorts for Oil Shale and Modern Boilers for Shale Coke", by Johansson and Hedback.

VISIT TO PLANT OF MESSRS SVENSKA MASKINVERKEN A.B.

At the termination of the visit to the Swedish shale oil plant at Kvarntorp, the Mission was invited by the Svenska Maskinverken A.B. to visit their steel works and boiler manufacturing plant at Kolsva.

The steelworks are small, but produce high grade steel in two induction and one arc furnaces. The main purpose of the visit was to inspect the manufacture of La Mont boilers and La Mont tubular goods at the boiler plant. Here the steam raising tube nests for the Kvarntorp retorts are made, and the adjacent foundry also supplies retort castings for the Swedish shale industry. The La Mont tube nests for the Kvarntorp retorts were being built up from standard lengths by resistance welding, but where this was not possible, electric arc welding was carried out by hand. The standard of workmanship appeared to be very high and the plant and buildings very clean and well maintained.

RECOMMENDATIONS OF THE MISSION

Many of the members of the Mission had not previously seen a shale oil plant in operation and all were impressed with the possibilities of development in their own countries in the future.

With the evidence that so much had been done in Sweden and elsewhere, and realising the complexity of the subject in relation to the varying physical and chemical characteristics of oil shales, the members were unanimous in the following recommendations:

1) That a Shale Oil Committee should be set up under the O.E.E.C. Organisation in Paris for the purpose of circulating information to and organising research by Member nations. The name of Mr. Quistgaard was proposed as Chairman of this committee.

2) That the Mission, having studied Swedish methods of shale oil production and issued its report, official interest in this potentially immense subject of shale oil should not be permitted to lapse. Recognising that favoured Swedish methods were specifically designed to handle a particular shale, further information should be sought and the scope of the investigation widened by the sending of a Mission to the United States to study the methods experimented on and the conclusions arrived at by the Shale Oil Research staff of the United States Bureau of Mines.

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(4) Johansson & Hedback — Recent Possibilities of Development by means of Modern Retorts for Oil Shale and Modern Boilers for Shale Coke.

Fourth World Power Conference, London, 1950, p. 4.

TABLE 1

ANALYSES OF FUEL OILS:

	Fuel Oil from Retort Crude.	Fuel Oil from Ljungstrom Crude
Sp. Gr. at 20° C.	1.00	0.94
Sulphur, % wt.	1.9	1.3
Flash Point, ° C.	78 approx.	88 approx.
" " ° F.	172 "	190 "
Viscosity at 20° C., c.s.	73	4.5
" " 50° C. c.s.	15	1.1
Setting Point, ° C.	-34	-80
Ash, % wt.	0.02	0.005
Asphalt, % wt.	0.60	0.25
Water, % vol.	0.1	0.1
A.S.T.M. Distillation		
I.B.P.	176° C.	197° C.
5% dist. at	211° "	220° "
10% " "	228° "	227° "
20% " "	261° "	241° "
30% " "	293° "	257° "
40% " "	320° "	269° "
50% " "	344° "	280° "

TABLE 2

ANALYSES OF CRUDE GASOLINES & SCRUBBER NAPHTHA

	Crude Gasoline from Retort Oil	Crude Gasoline from Ljungstrom Oil	Scrubber Naphtha (Debutaniser Bottoms)
Sp. Gr. at 20° C.	.790	.780	.710
A.S.T.M. Distillation			
I.B.P.	49° C.	36° C.	45° C.
5% dist. at	90° "	69° "	53° "
10% " "	101° "	83° "	56° "
20% " "	111° "	96° "	64° "
30% " "	119° "	108° "	68° "
40% " "	125° "	119° "	76° "
50% " "	132° "	131° "	88° "
60% " "	139° "	143° "	95° "
70% " "	149° "	155° "	109° "
80% " "	158° "	171° "	124° "
90% " "	178° "	195° "	152° "
95% " "	195° "	215° "	174° "
F.B.P.	218° "	243° "	185° "
Total Sulphur in 170° C. Fraction, % wt.	1.2/1.3	0.8/0.9	1.5/1.6
Sulphur as CS_2, % wt.	Approx. 0.05	—	Approx. 0.70
Iodine Number (Hahl)	Approx. 150	Approx. 60	Approx. 160

TABLE 3

ANALYSES OF GASOLINE AND POWER KEROSINE

	Motor Gasoline	Power Kerosine
Sp. Gr. at 20° C.	.730	.870
A.S.T.M. Distillation :		
I.B.P.	47° C.	188° C.
5% dist. at	60° "	199° "
10% " "	66° "	203° "
20% " "	81° "	206° "
30% " "	92° "	209° "
40% " "	110° "	212° "
50% " "	121° "	215° "
60% " "	131° "	217° "
70% " "	141° "	221° "
80% " "	157° "	227° "
90% " "	171° "	236° "
F.B.P.	207° "	—
Total distillate	98.5%	—
Sulphur, % wt.	0.20 max.	1.2
Free Sulphur	Nil	Nil
Doctor Test	Negative	Negative
Gum, mgm./100 mls.	1	—
Vapour Pressure, kg./sq.cm.	0.3	—
" " p.s.i.	3.2	—

TABLE 4

REFINING SCHEME AT KVARNTORP

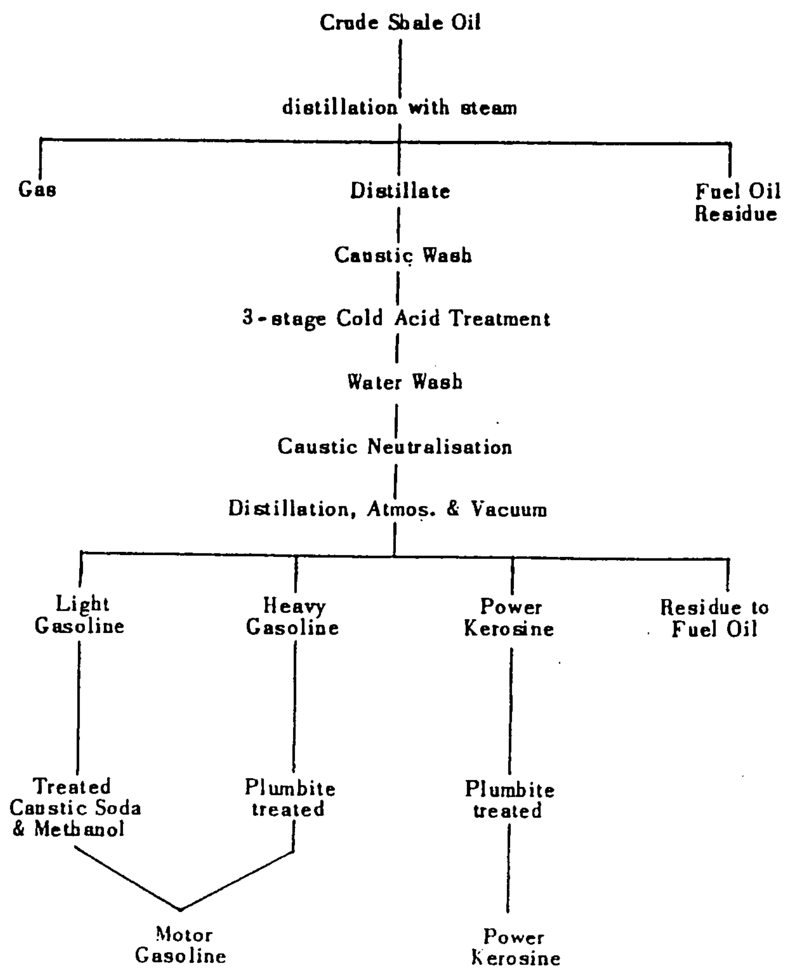


TABLE 5

ANALYSES OF RETORT GASES:

		Bergh Retort	I.M. Retort	H.G. Retort	Ljungstrom Field
H_2S	%	16	28	14	25
CO_2	"	10	8	12	5
CO	"	1	1	1	0.5
O_2	"	0.5	0.2	0.5	0.1
N_2	"	35	12	25	2
CnH_{2n}	"	3.5	10	4	4
$CnH_{2n}+2$	"	19	26	17	46
Calorific Value:					
K.Cals./cu.m.		4984	5287	4806	8989
B.T.U./cu. ft.		560	594	540	1010
Volume: Cu.m/ton		54.36	36.24	109.01	9.74
cu. ft./ton		1920	1280	3850	344

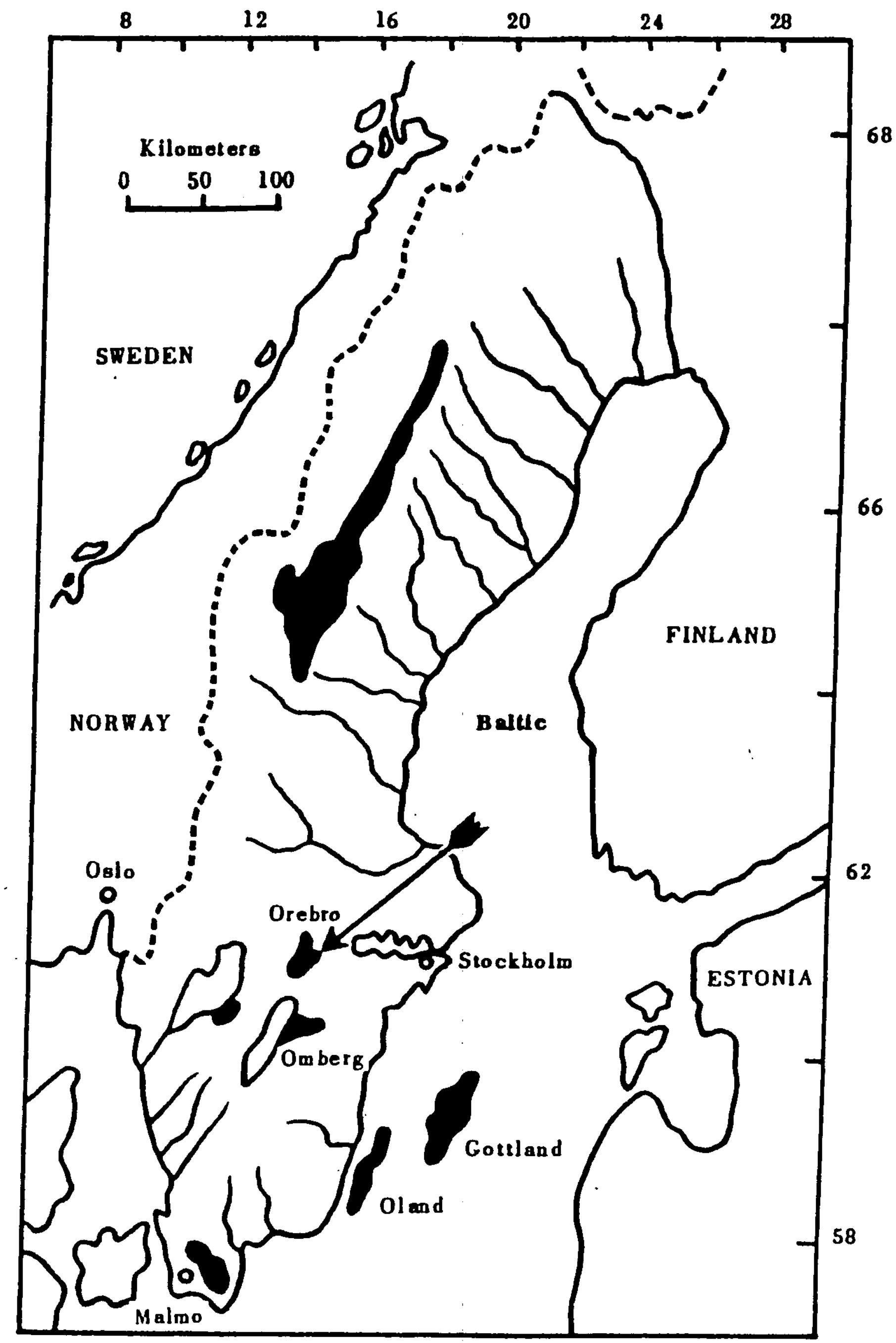


FIG. 1 – Map of Sweden showing principal Shale Deposits.

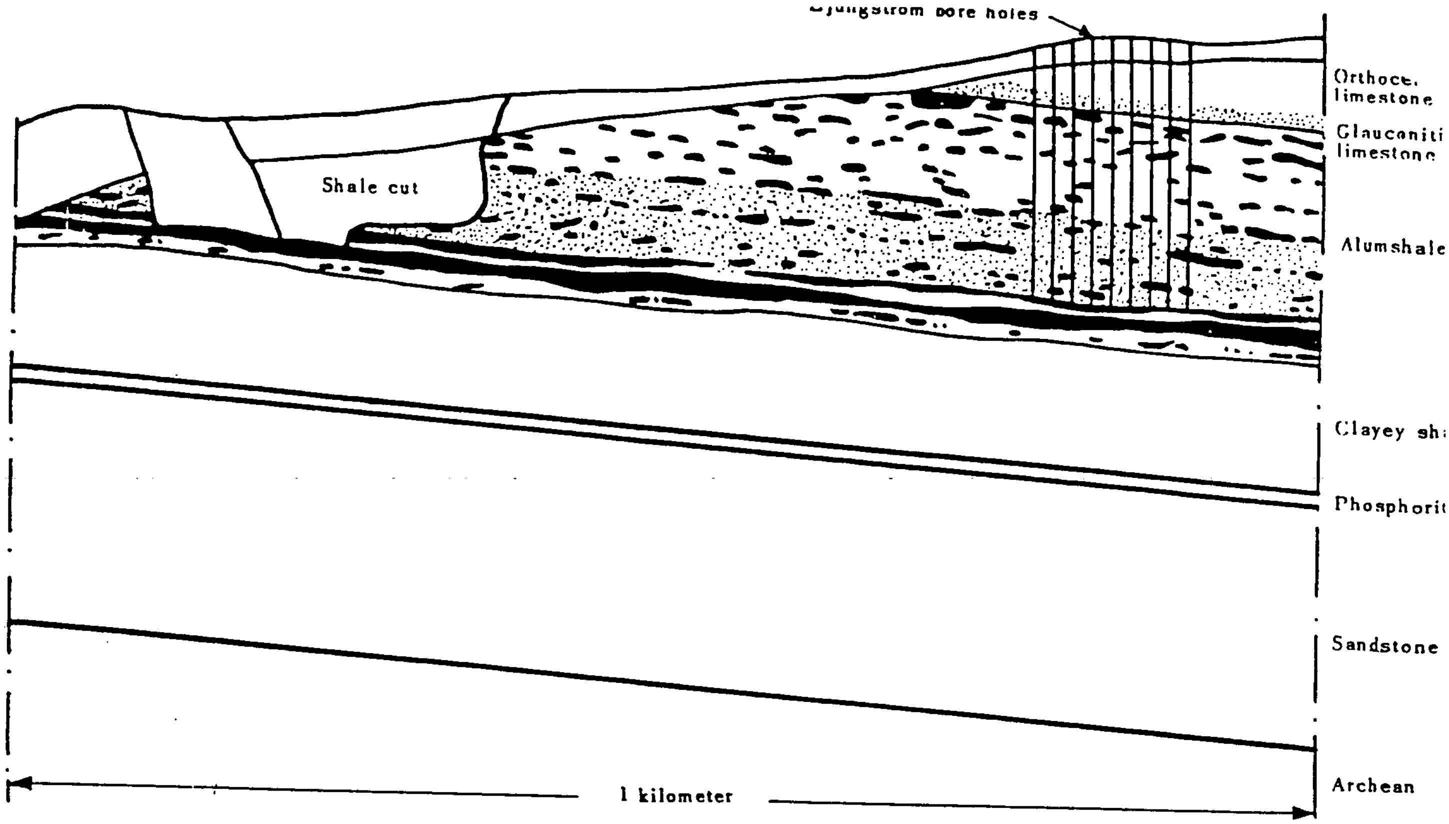


FIG. 2 – Cross Section of Strata at Kvarntorp.

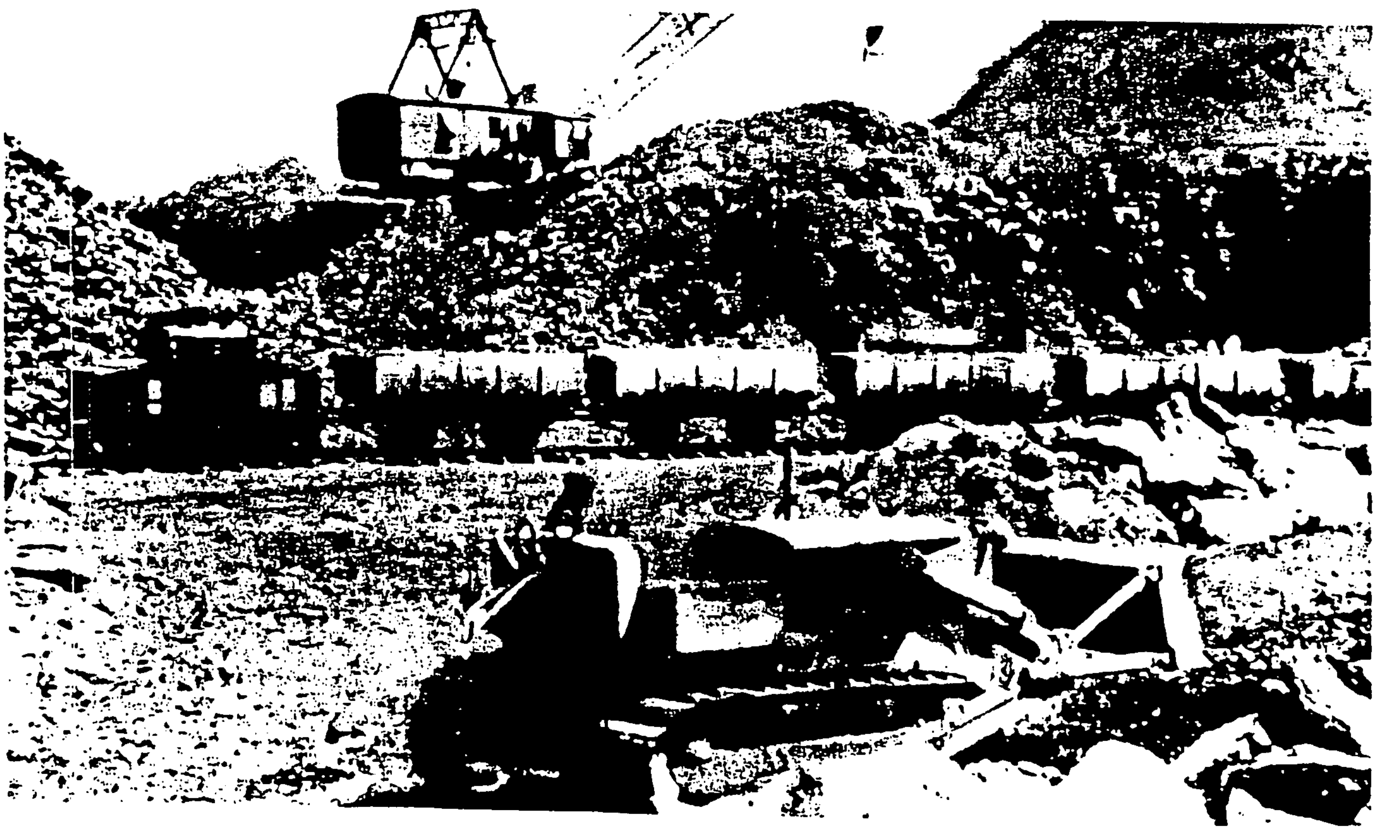
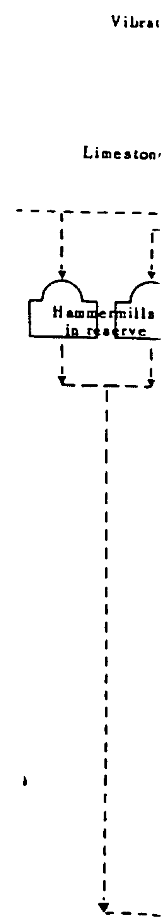


FIG. 3 – Drag Line, Mechanical Shovel and Trai: , at Shale Workings.

FIG. 4 – Picking of Limestone from Shale.

FIG. 5 – Silos for Crushed and Graded Shale.



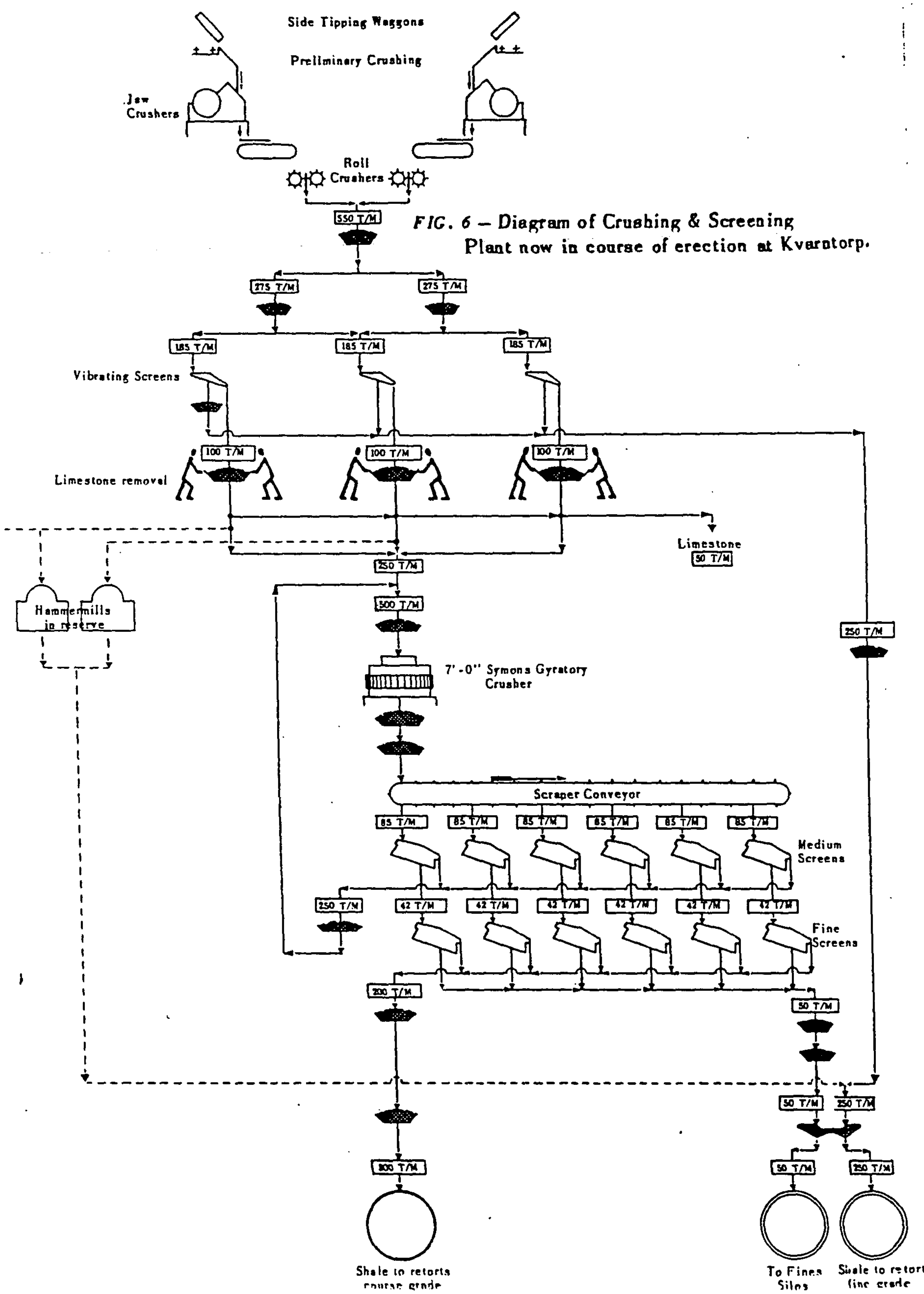


FIG. 6 – **Diagram of Crushing & Screening Plant now in course of erection at Kvarntorp.**

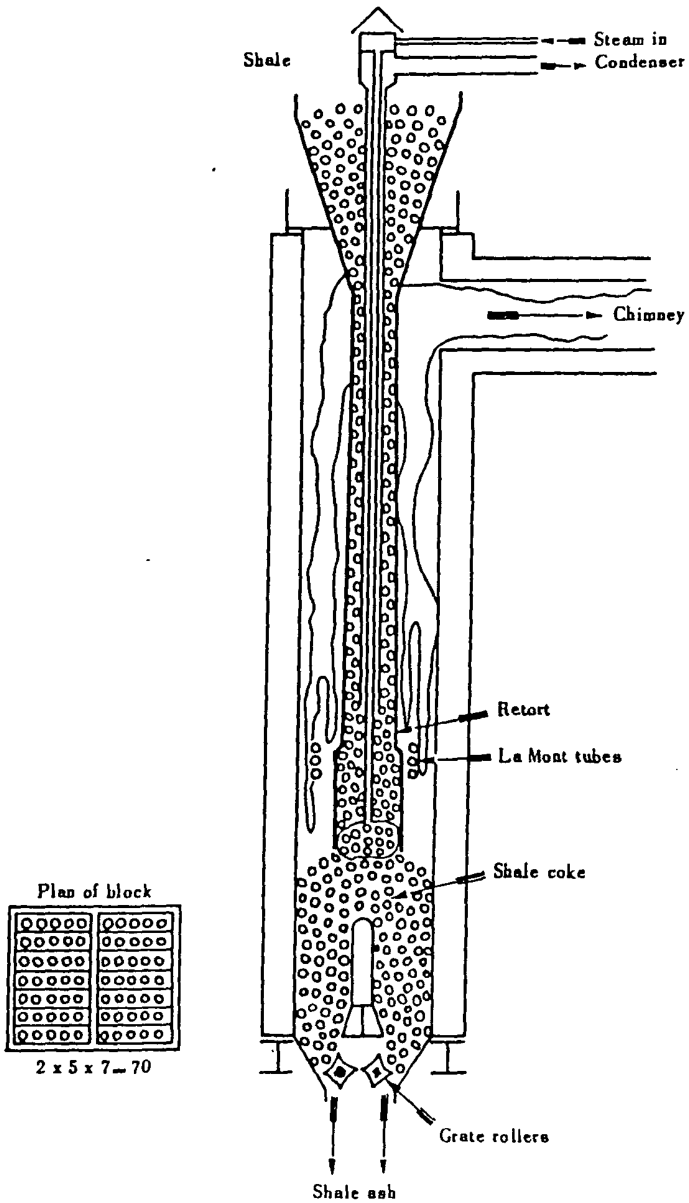


FIG. 7 – Cross Section of Bergh Retort.
Plan of Retort Block of 70 retorts shown on left.

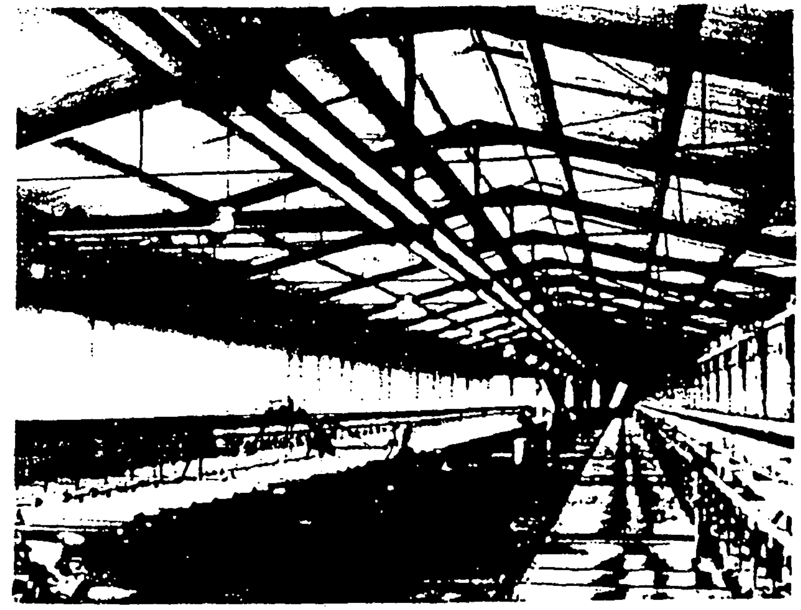


FIG. 8 – **Charging Platform in Kvarntorp Retort House.**

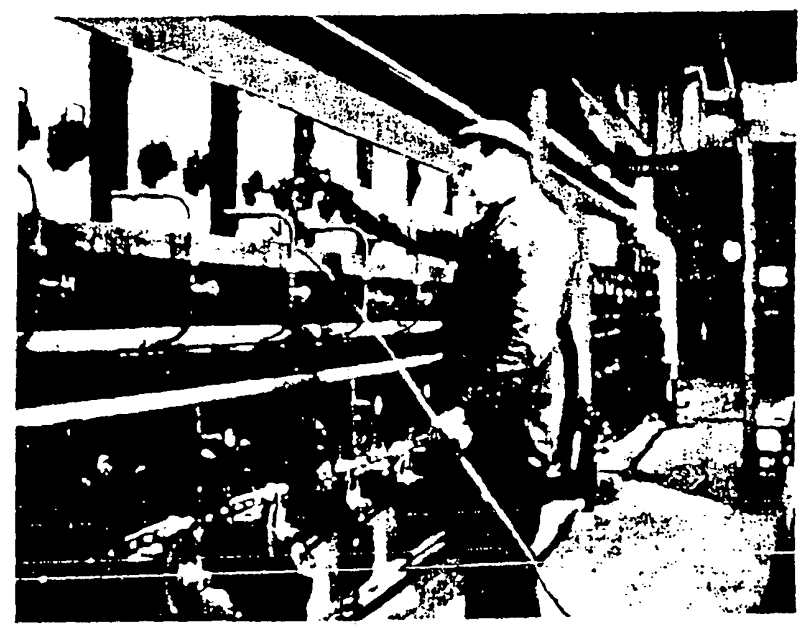


FIG. 9 – Kvarntorp Retort Bench, showing Extr[illegible]n Gear.

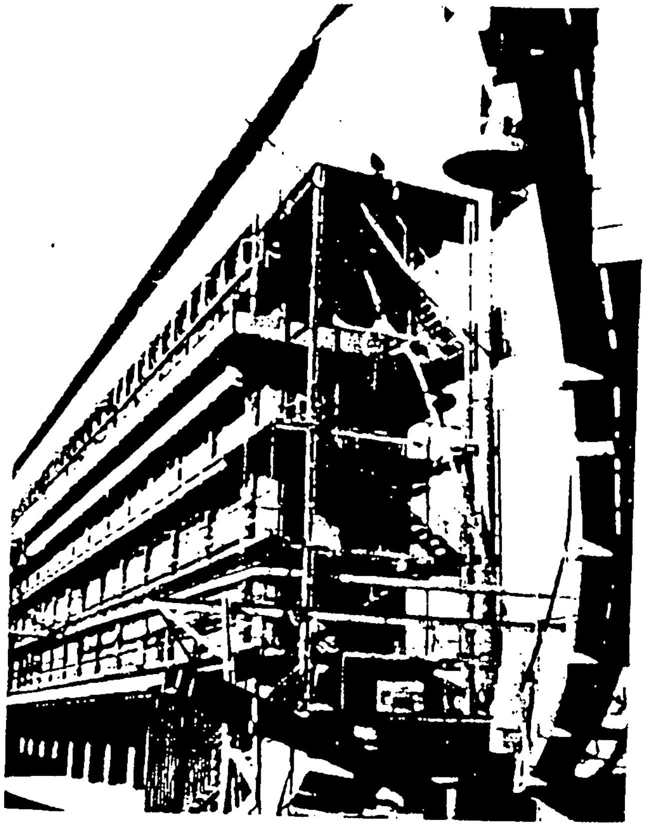


FIG. 13 – The Bench of H.G. Retorts at Kvarntorp.

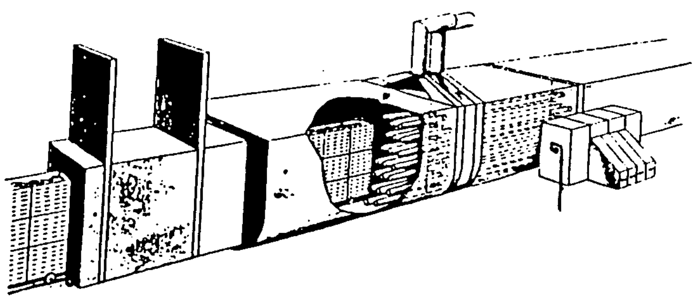


FIG. 14 – The I.M. Retort or Tunnel Kiln.

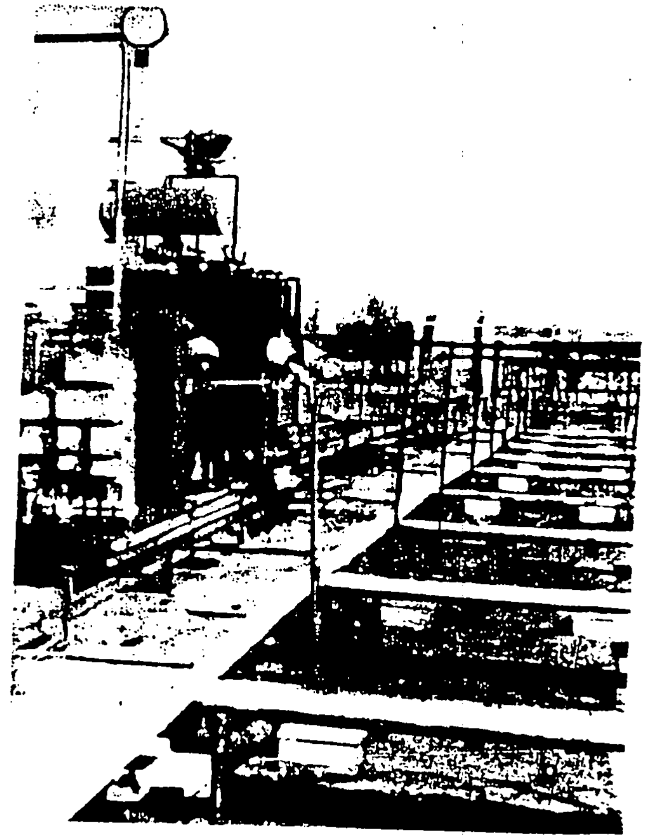


FIG. 15 – The Ljungstrom of Oil Recovery.

Mobile Transformers Supplys Cables and Va Collecting Tubes

FIG. 16 – Air cooled Condensers in Ljungstrom Area.

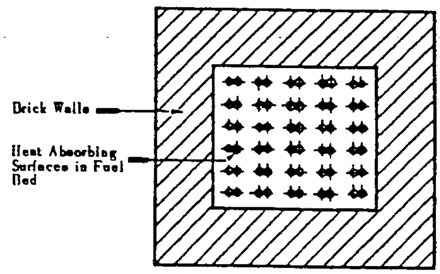


FIG. 17 – Cross section of Experimental Coke Burning Furnace.

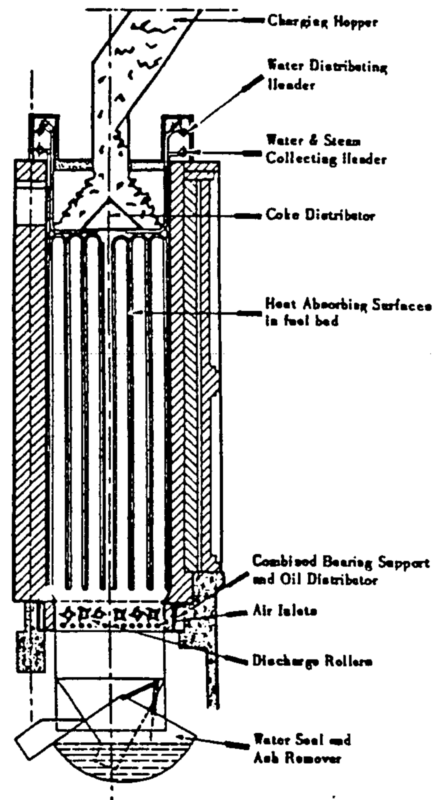


FIG. 18 – Cross Section of Coke Burning Furnace in use at Kvarntorp.

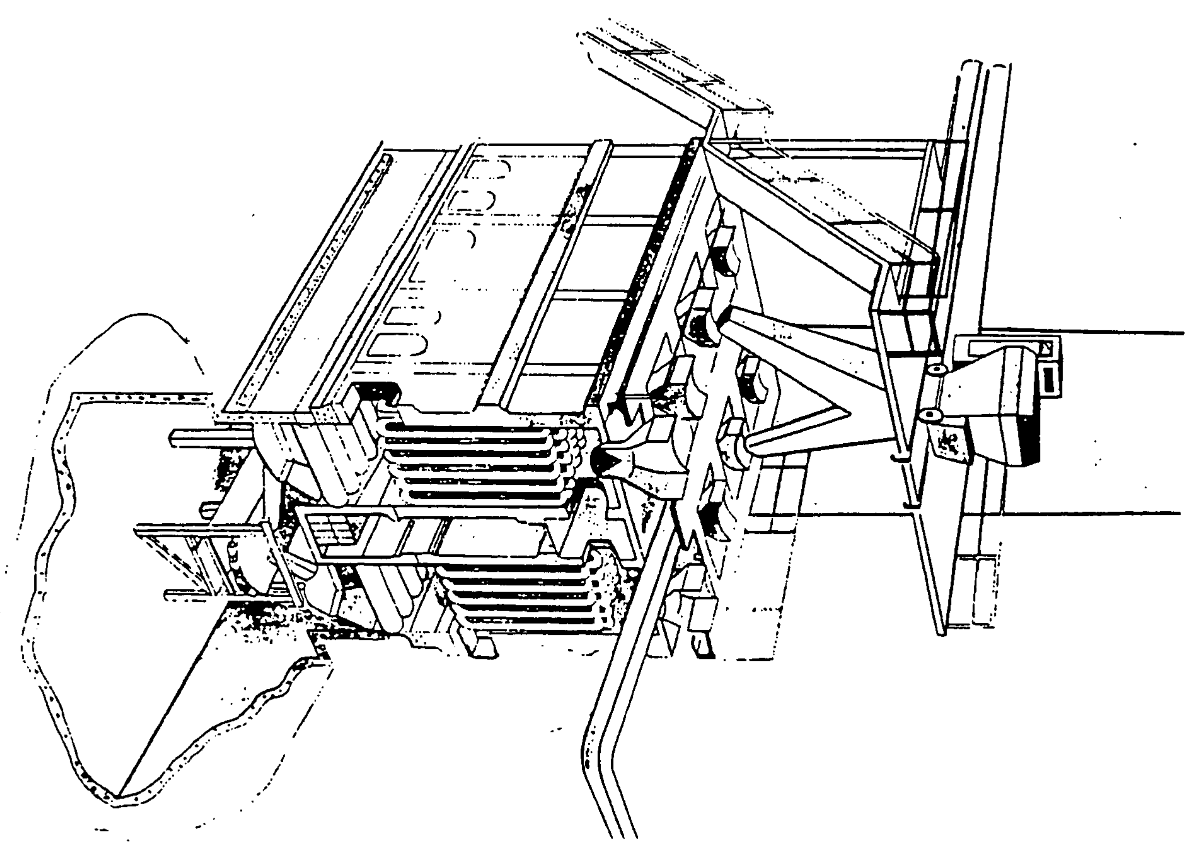
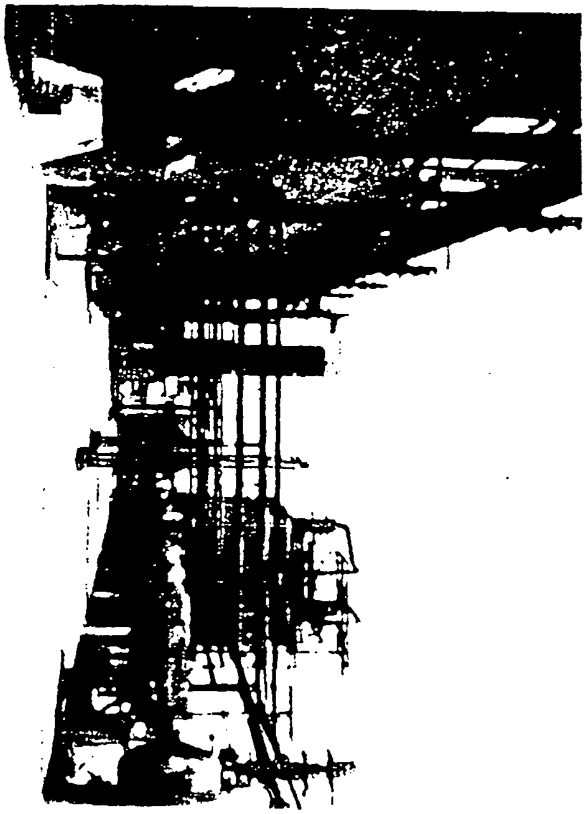


FIG. 19 – Part Section of a Block of Coke Burning Fur 's, showing charging and discharging arrangements, steam generating tubes, etc.



21 – Acid and Soda Washery showing contact towers and sludge tanks.

FIG. 20 – A Bench of 24 Coke Burning Furnaces.

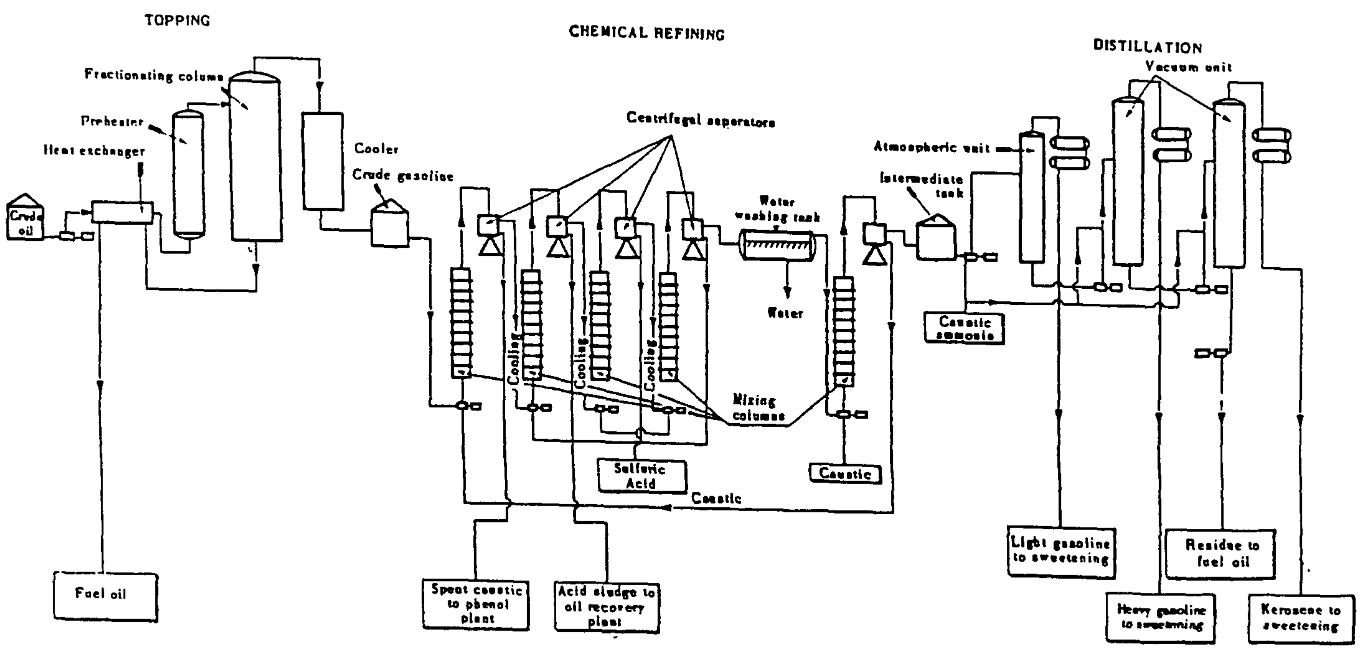


FIG. 22 – Flow Diagram of Refining Scheme employed at Kvarntorp.

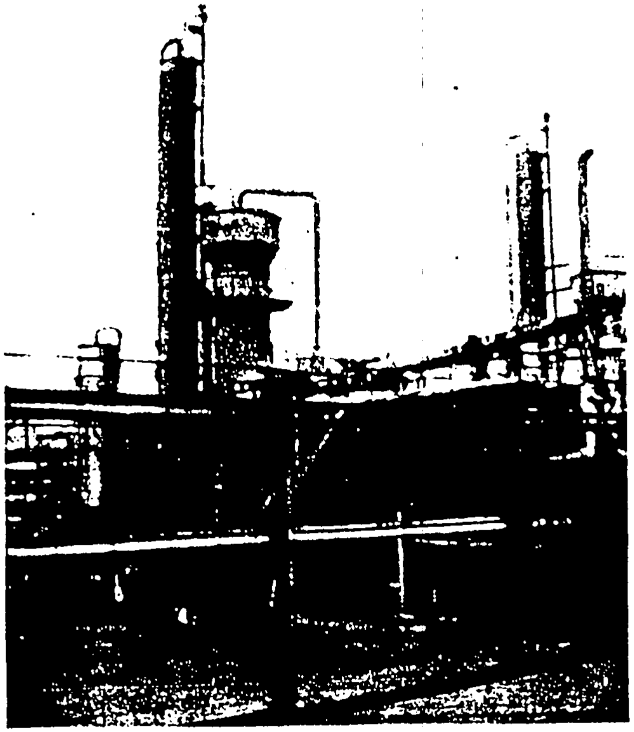
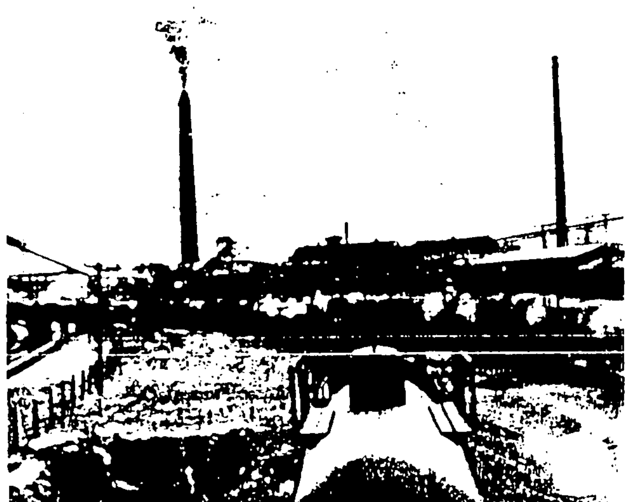
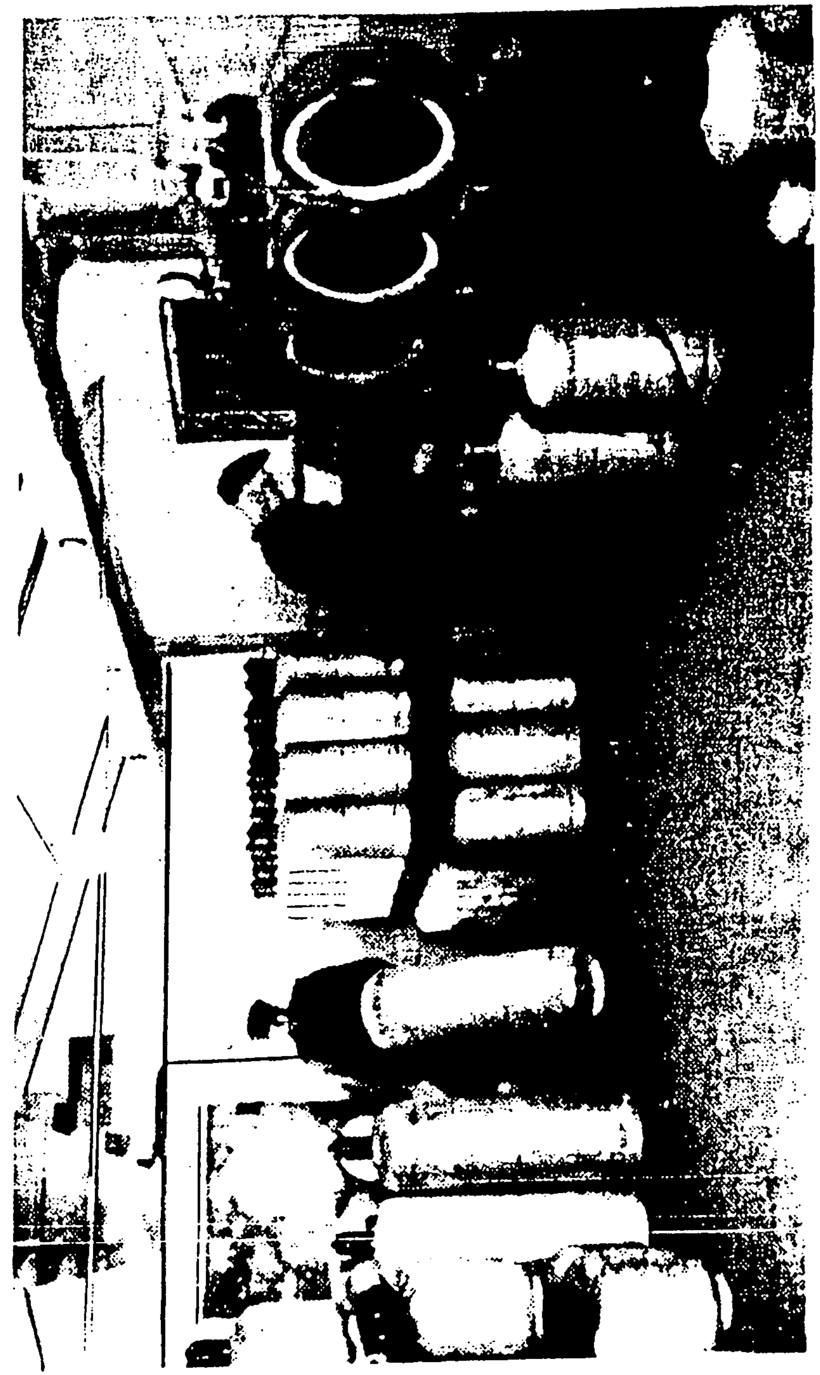


FIG. 23 – Rail Transport of Oil Products.



IG. 24 – A Sulphur Recovery Unit.



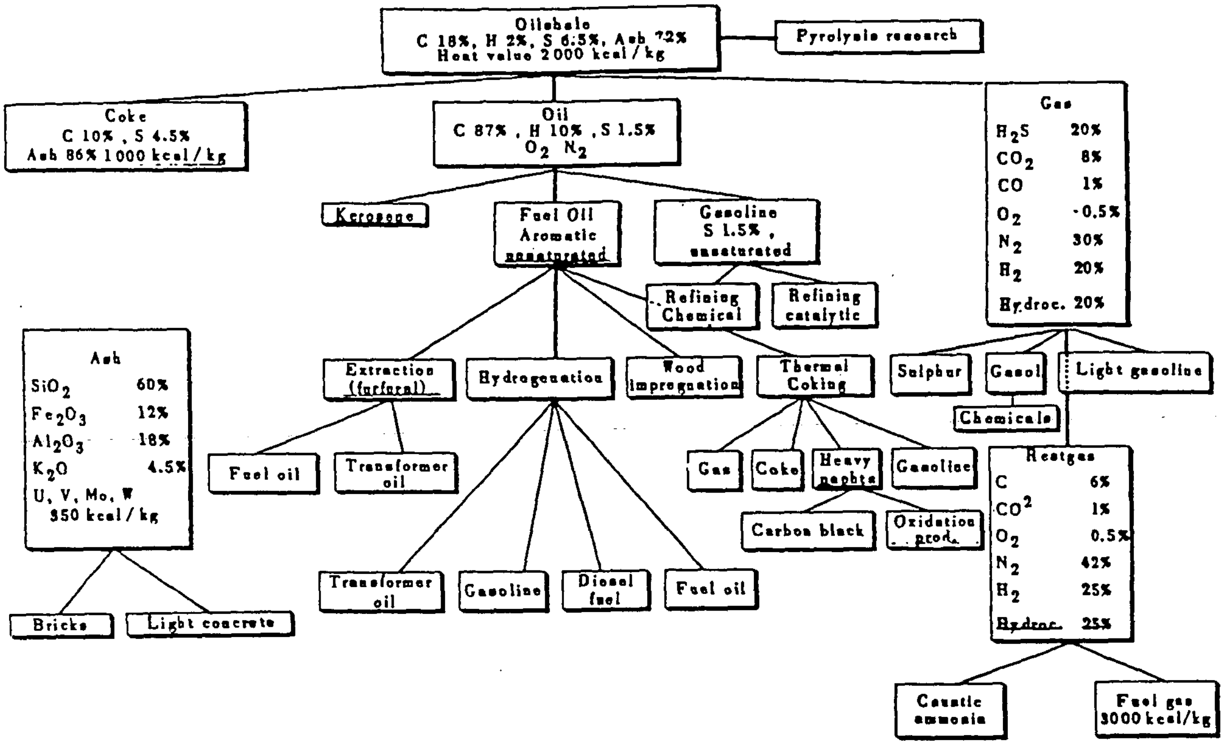


FIG. 26

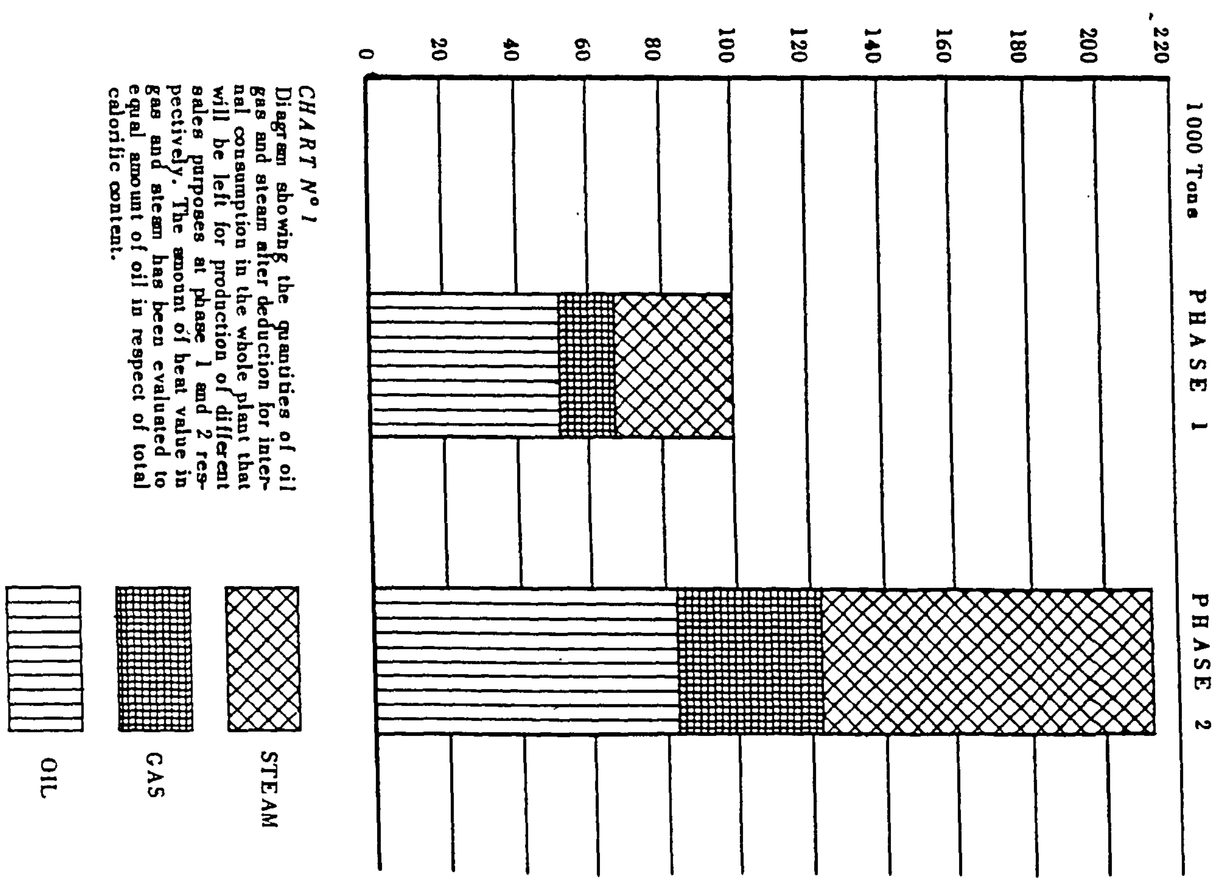


CHART N° 1

Diagram showing the quantities of oil gas and steam after deduction for internal consumption in the whole plant that will be left for production of different sales purposes at phase 1 and 2 respectively. The amount of heat value in gas and steam has been evaluated to equal amount of oil in respect of total calorific content.

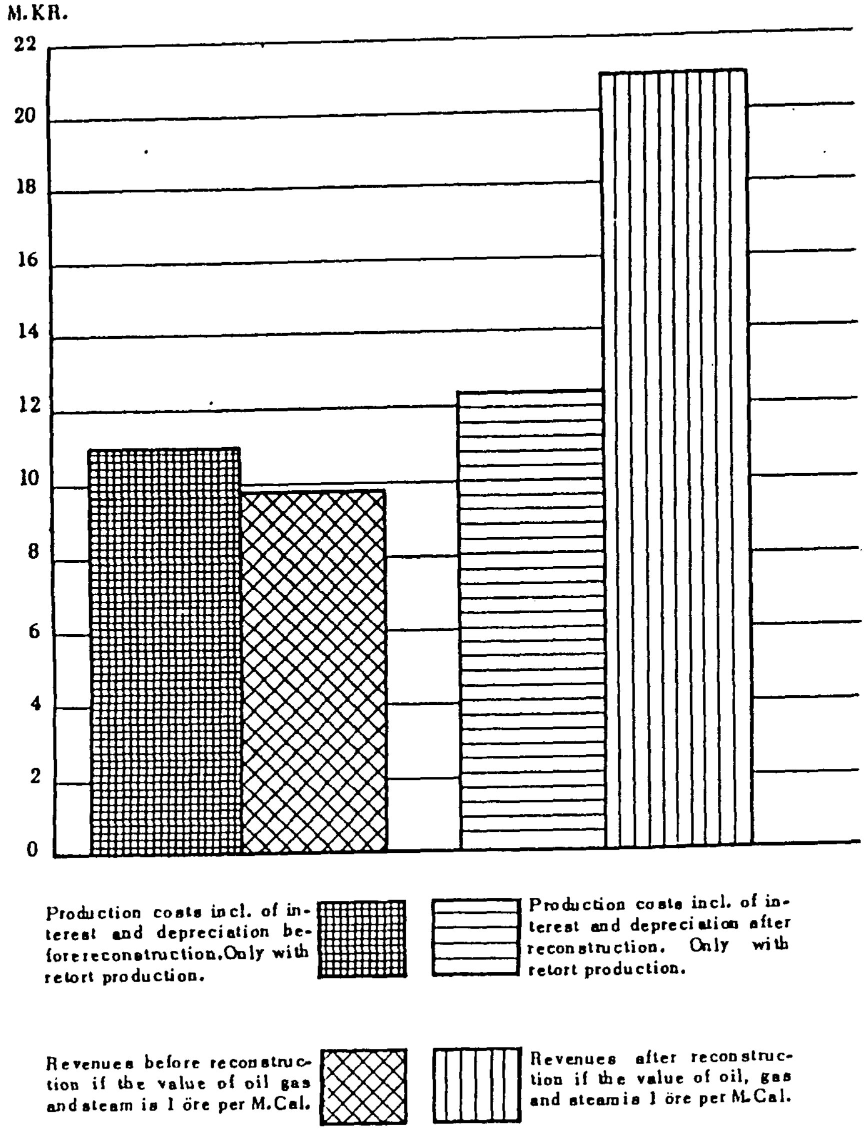


CHART N° 2

This diagram illustrates the theorical conditions that would be available if the plants only were built for shale mining together with retorts for distillation without the production of by-products.

It is calculated that the total amount of producer gas and steam is marketed at a price of 1 Sw. öre/M.CAL. i.e. about Sw. Cr. 100 per ton of oil or Sw. Cr. 65 per ton of coal.